MulDar

Unleashing the Potential of Distributed COTS mmWave Radar by Exploiting Cross-Device Channels

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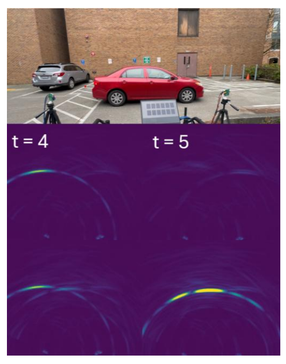
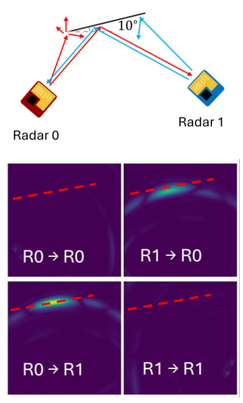
Fundamental Limitations of mmWave Radars

mmWave Radars are used for its low-cost, privacy-preserving, high-bandwidth and good range and velocity resolution. However, practical deployments are still limited to simple interactions while research has built advanced functionalities such as full-body pose reconstruction, non-contact vital sign sensing.

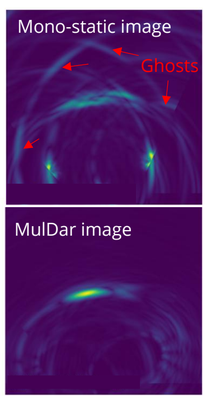
Problem towards practicability: Sparse and Noisy Information



Vague and incomplete shape due to low-angular resolution



Invisible items and due to specular reflection



Ghost responses due to multi-path

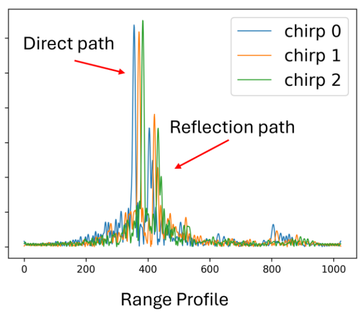
Enabling Cross-Device Channels & Distributed Radar Phase-level Synchronization

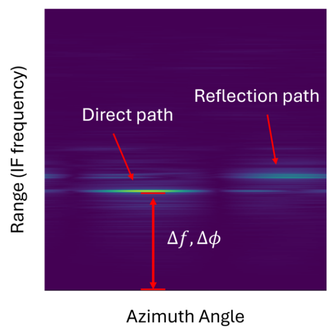
MulDar tries to solve the problem by enabling cross-device channels for 77GHz radars that's already been deployed without any hardware modification or expensive RF chain distribution.

For n radars each has A transmitters and B receives we increased the number of channels from $\mathbf{n}AB$(mono-static) to $\boldsymbol{n^2}AB$ (MulDar)

--> Fundamentally increases the information received

Challenge: Synchronizing mmWave radars (76-81 GHz in our work)

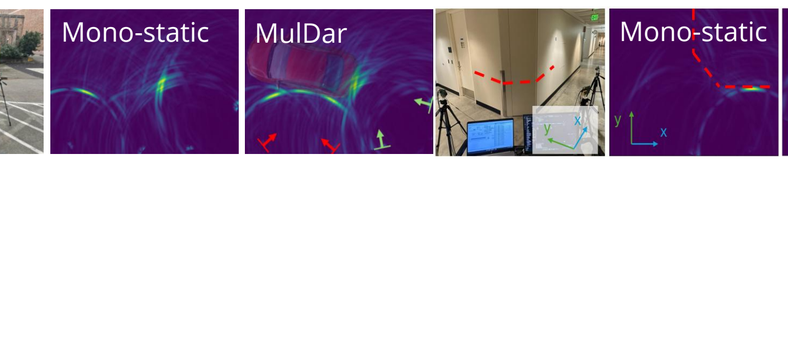




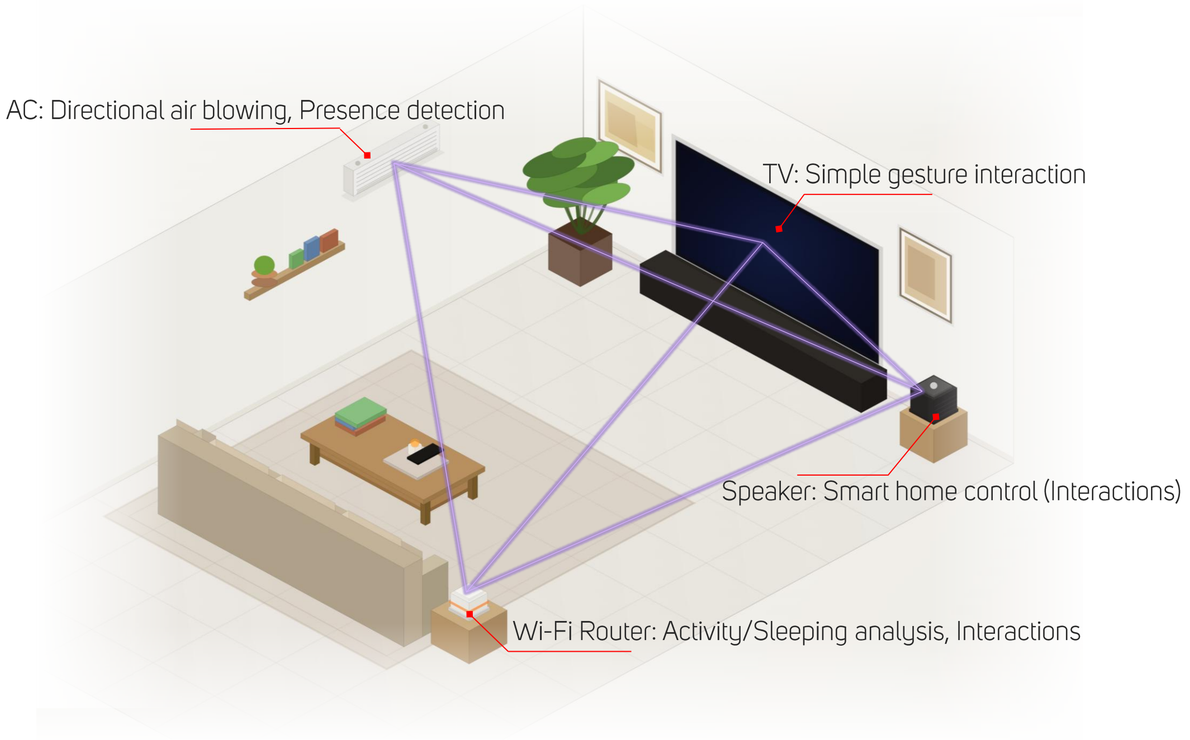
Coarsely synchronized multi-static chirps.
Every chirp is subject to different frequency, phase and amplitude offsets, which hinders cross-device (multi-static) imaging.

Solution:

Hardware triggering (Coarse synchronization)
+ Direct-path-referenced correction (Phase-level synchronization)



Synchronization Error Analysis

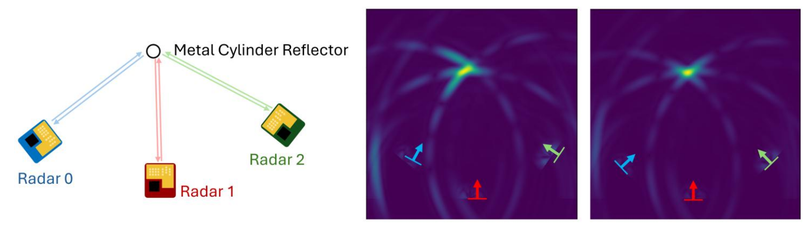


Common mmWave applications in smart home scenario
MulDar enabled 77GHz cross-device imaging without hardware modification

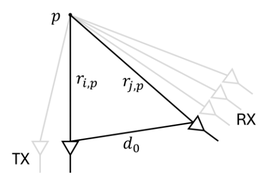
Sparse Multi-Static Radar Array Imaging

The synchronized distributed radars forms a sparse multi-static radar array. MulDar use back-projection method (a matched-filtering method) for scene reconstruction that calculates the amplitude at each pixel across the imaging plane.

We first use a metal cylinder for calibrating the radar poses. Manually measured inaccurate radar poses will distort the generated image.



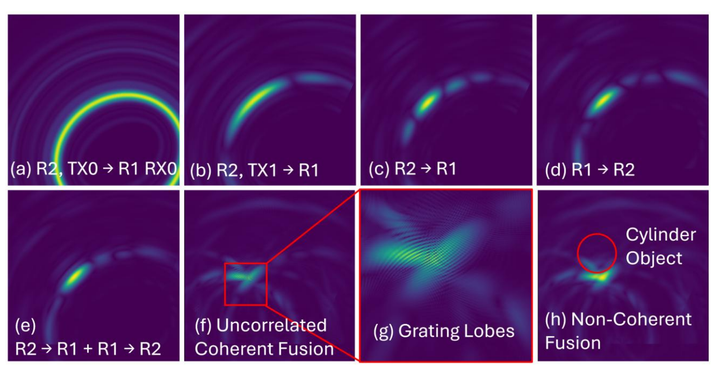
Matched filter distance calculation with a different bi-static geometry considering the location of TX and RX.



$$\mathbf{s}(\mathbf{p}) = \sum_{i=0}^{A}\sum_{j=0}^{B} S_{i,j}\left(\frac{\rho_{i,j,p}}{\Delta r}\right)e^{j2\pi\rho_{i,j,p}/\lambda_0}$$

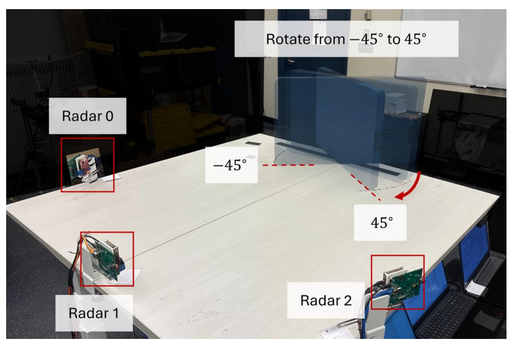
$$\rho_{i,j,p} = r_{i,p} + r_{j,p} - d_0$$

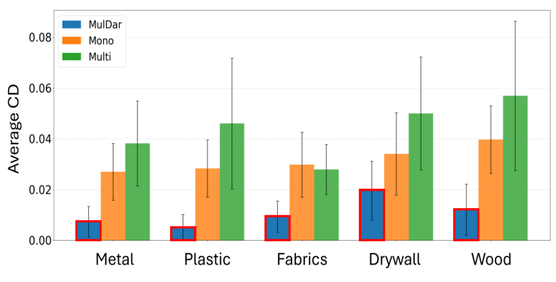
MulDar non-coherently combine mono-static and multi-static images generated by each channel. Coherent combination of sparse array induces grating lobes that harms the image quality.



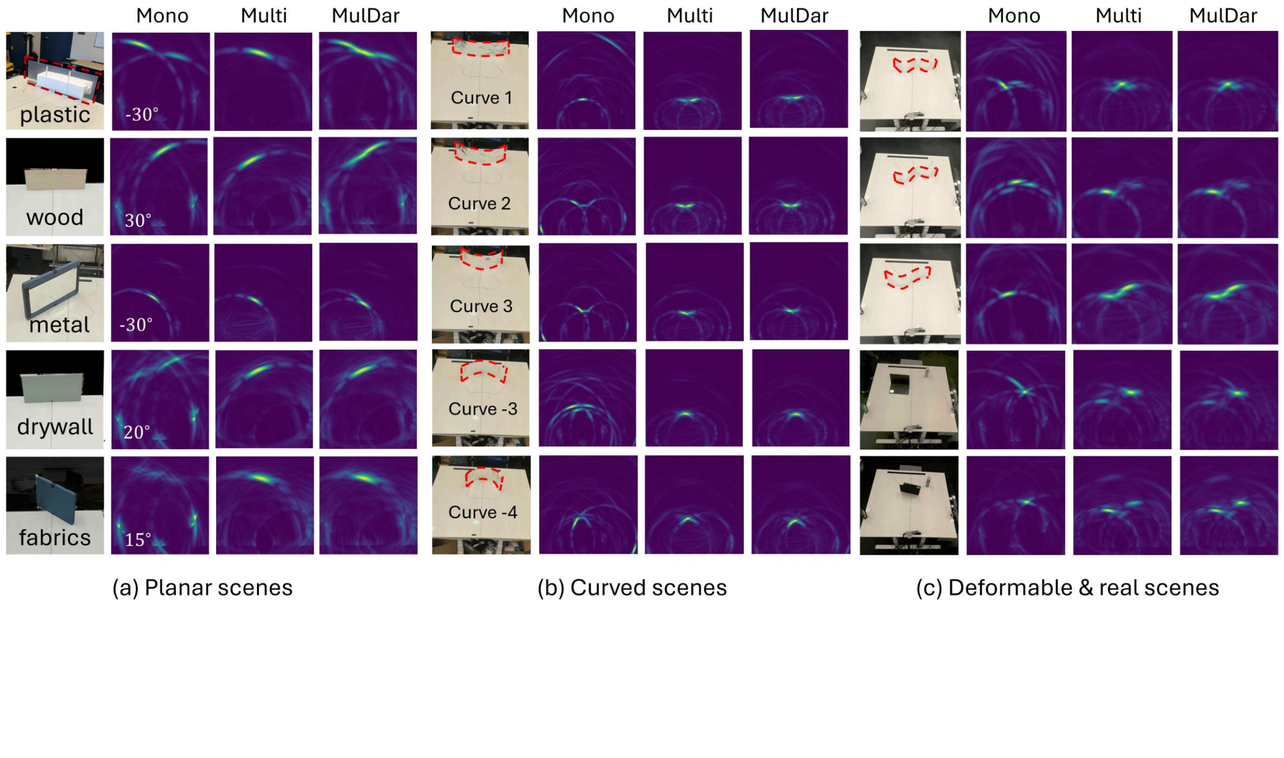
MulDar is the non-coherent combination of mono-static and multi-static channels

Evaluations





Average two-way chaffer distance of estimated pc and ground-truth pc



(a) Planar scenes (b) Curved scenes (c) Deformable & real scenes