Thank you, Professor,

Hello everyone. My name is Josiah Smith and I’m excited to share with you this research on MIMO-ISAR millimeter-wave imaging in the near-field.

In this presentation, I’m going to guide you through the innerworkings of our fully integrated rotational ISAR system, overviewing the system model, algorithms, prototype scanner, and experimental results.

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Millimeter-wave sensors have recently emerged as a promising solution to a variety of sensing problems in the arenas of security sensing, automotive radar, high-resolution imaging, and many more. Additionally, millimeter-wave radar devices are becoming increasingly affordable due to advancements in system-on-chip RF integrated circuit technology.

Radar imaging systems hold the distinct advantage over optical systems as they can be used for non-line-of-sight imaging.

The goal of this work is to construct a high resolution mmWave imaging system for near-field holographic 3-D image reconstruction using novel ISAR techniques and commercially available mmWave radar sensors.

This system can reconstruct high-resolution images of metal and plastic items occluded inside of cardboard boxes or hidden inside personal baggage, making the rotational ISAR scanner an ideal fit for industrial packaging and security sensing applications.

To accomplish this goal, we develop an efficient Fourier-based algorithm for MIMO-ISAR image reconstruction and build a three-dimensional mechanical scanner to synthesize both rectangular and cylindrical apertures. Our novel approach uses time-efficient MIMO array scanning without requiring a computationally taxing multistatic image reconstruction algorithm.

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First, I will overview the rotational ISAR configuration. Our system consists of three main components: a linear vertical scanner, rotator, and FMCW radar. The linear mechanical scanner moves the radar along the *y*-axis up and down. The target is mounted to the rotator, which rotates at a constant radial distance from the radar scanning plane. This rotation pattern synthesizes a vertical cylindrical array surrounding the target. The radar we are using is a TI mmWave radar with 2 Tx and 4 Rx channels resulting in an 8-channel colinear multistatic-MIMO virtual array.

I’ll now overview the scanning pattern.

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First, the radar captures the target while it is rotating.

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Then, the radar is moved vertically by the scanner.

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And the rotation begins again.

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This pattern repeats until the full cylindrical aperture is synthesized.

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In order to take advantage of the 8 channel MIMO array on the TI radar, we have to overcome some phase errors introduced by the multistatic array.

Even though the multistatic MIMO array can be approximated by a virtual array of elements at the midpoint of each transceiver pair, the multistatic nature of the MIMO radar introduces phase errors compared to the virtual monostatic array.

However, for small distances between Tx and Rx elements, these errors can be compensated for using a phase correction expressed below. This multistatic-to-monostatic conversion enables the use of spatially efficient MIMO arrays and computationally efficient monostatic image reconstruction algorithms.

Finally, based on the mathematical model, we derive an image reconstruction algorithm for the rotational ISAR scenario using the approximate monostatic signal. Our algorithm leverages the fast Fourier transform to reconstruct the 3-D holographic image much faster than the matched filter method used in the literature. Pairing this efficient algorithm with the multistatic-to-monostatic conversion, we can take advantage of both faster scanning and more efficient image reconstruction.

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To validate our proposed MIMO-ISAR algorithm, we simulate the point spread function by placing a point target off the rotator axis. The ideal point reflector, simulated point spread function, and slices along the x-z and x-y planes show the imaging performance of our method.

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Finally, we assemble a fully integrated system with vertical, horizontal, and rotation scanning capabilities allowing for comparison between rectangular SAR and rotational ISAR. The entire scanner is controlled through a custom-built MATLAB graphical user interface that sets up the radar device and controls the scan.

We will proceed to reconstruct high resolution holographic images of the knife shown to the right. Note the notch and serrated edge of the blade, which will be visible in the subsequent images.

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We first compare images from a SISO array of 512 quasi-monostatic vertical elements spaced by a quarter wavelength. Since we are using a SISO array, the scan at each of the 512 vertical locations took 137 minutes to complete. In contrast, the scan using a MIMO array of the same size took 17 minutes in total. Both the images show a high-quality reconstruction of the knife blade with the notch and serrated edge visible.

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Next, we use the 2-D horizontal and vertical scanning axes to produce 3-D holographic images from a rectangular SAR aperture. We consider two cases. First, if the knife blade is parallel with the x-y aperture plane, and second, when the knife blade is perpendicular to the x-y plane. The orientation of the knife with respect to the scanner has substantial implications on the image quality.

The images on the right compare the reconstructed images of the knife blade when the knife is parallel and perpendicular to the scanning plane.

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This demonstrates the high dependence of the image quality on the knife orientation in the rectangular MIMO-SAR regime. While rectangular SAR can reconstruct high-resolution 3-D images of reflective targets, the rotation of the target drastically changes the quality of the resulting image.

By comparison, rotational MIMO-ISAR is rotation-invariant since the target is scanned across a full 360-degree aperture. Further, this results in improved spatial resolution over the rectangular SAR imaging regime.

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In conclusion, we developed a high resolution 3-D near-field imaging system based on low-cost system-on-chip mmWave FMCW radars, a multistatic-to-monostatic conversion, and an efficient Fourier-based rotational ISAR imaging algorithm.

Our experimental results validate our novel MIMO-ISAR 3-D holographic image reconstruction algorithm, demonstrate improved scanning efficiency over SISO systems, while maintaining high-resolution image quality, and establish the rotational-invariance advantage of rotational ISAR over rectangular SAR.

Proved by simulation and empirical measurement, our fully integrated system allows for efficient near-field MIMO-ISAR mmWave imaging offering an elegant solution to many near-field imaging and sensing problems.