A Digital Interferometric Array with Active Noise Illumination for Millimeter-Wave Imaging at 13.7 fps

S. Vakalis* and J. A. Nanzer

Michigan State University, East Lansing, MI, USA
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Introduction

- Millimeter-wave radiation for imaging
  - Good penetration through many materials and non-ionizing radiation
  - Components are getting increasingly cost-effective
  - Multiple applications including security screening, automotive, and medical imaging

Motivation

• Increased need for security screening
  – Contraband detection
  – Smuggling and drug trafficking
  – Non-contact

• Considerable room for improvement
  – Current state of the art is not fast enough
  – Electrical scanning arrays can be costly
  – Many techniques not suitable for real-time

[3] https://www.flickr.com/photos/33671002@N00/5782904251
Interferometric Imaging

- A 2D image can be decomposed into a set of spatial frequencies and complex amplitudes.
- A distributed antenna array can capture those signals corresponding to different spatial frequencies.
Interferometric Image Formation

Interferometric Imaging

- Sparse arrays
- Improved spatial resolution
- No need for scanning
- Tolerance to element failures
- Distributed aperture

However: interferometric imaging systems have been traditionally passive
But why passive systems?

• In radio astronomy the radiation requirements were referred as the Van Cittert-Zernike theorem [5]

\[ V_1 = s_{1A} + s_{1B} + n_1 \]
\[ V_2 = s_{2A} + s_{2B} + n_2 \]

\[ V_{out} = \langle V_1 V_2 \rangle = \langle s_{1A}s_{2A} \rangle + \langle s_{1B}s_{2B} \rangle + \langle s_{1A}s_{2B} \rangle + \langle s_{1B}s_{2A} \rangle \]

\[ V_{out} = \langle V_1 V_2 \rangle \approx \langle s_{1A}s_{2A} \rangle + \langle s_{1B}s_{2B} \rangle \]

Active Imaging Benefits

- Lower sensitivity receivers
- Smaller bandwidth
- Shorter integration time
- However: the transmit radiation should be incoherent in both space and time
- Our solution: **noise transmitting array**
Microwave measurements

Using only 25 MHz of bandwidth and 10 $\mu$s of integration time.
Passive systems use cryogenically cooled detectors, but can we do everything digitally?

Millimeter-wave measurements

Distributed digital array architecture

Element level digital
Experimental Setup

- Cost effective system
  - 16 x 3D printed horn antennas
  - 3 x noise transmitters
  - Commercial mm-Wave hardware
  - 2 x 16Ch-digitizers connected to a PC
Signal Processing Algorithm

- Fast signal processing based on vector multiplication and FFT
- No inverse problem needs to be solved
- Very fast, the bottleneck of the system is:
  - Data acquisition
  - Video plotting
Experimental Measurements at 13.7 fps
Conclusion

• A novel work was presented using element level digital interferometric array processing and incoherent noise transmission
• Computationally efficient processing and an easily expandable distributed architecture.
• Video rate millimeter-wave imagery at 13.7 fps can benefit multiple applications.
Contact Information for Further Questions

• Contact Information for the speaker is provided below for any follow-up questions:
  – vakaliss@msu.edu