Interferometric Imaging through Cluttered Media Using Electromagnetic Interferometry on a Hardware-Accelerated High-Performance Cluster

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Introduction

- Motivation
  - Detecting concealed objects such as weapons behind cluttered media is essential for security applications.
  - Terahertz frequencies are usually employed for imaging in security checkpoints due to their safe non-ionizing properties for humans and their ability to penetrate clothing while still reflecting off metallic objects [1],[2].
  - Interferometric images of target objects are constructed based on the complex correlation function of the received electric fields from the medium of interest at each pair combination of sensors in a detector array.
  - This imaging technique requires intensive computations which make it impractical for real-time security applications.

- Objectives and Approach
  - Provide a first effort, to the best of our knowledge, to efficiently implement and achieve a high performance of terahertz interferometric imaging of targets behind cluttered media using HPC platforms.
  - Explore the capabilities of a 13-node GPU-accelerated cluster using CUDA and MV APICH2 environments.
  - Maximize system resource utilization through efficient load balancing.

Interferometric Imaging through Cluttered Media

- Interferometric images are constructed using complex correlations of electric field intensities obtained from all possible pair combinations in a detector array [3],[4].
- The entire image is equally divided into many partial images and processed by the corresponding computing nodes.
- GPUs do all computations.
- CPU: data transfer and work distribution.

where \( \tau \) : the time average of the electric field intensity detected for each pixel.

- Target behind cluttered media: the electric field received at detectors have three contributions: direct scattering, indirect scattering, and volume scattering, and volume scattering.

Simulation Setup

- Detector and geometry:
  - Fixed distance-to-detector array
  - Frequency: 600 GHz

Detector Geometry

Target Image

Metrics for Evaluation

- Total execution time:
  - Speedup: performance gain when using multiple GPU-accelerated computing nodes in reference to a single GPU-based mode.
  - Scalability: normalized speedup.
  - Hardware efficiency: compares the execution time measured through experiments to the expected theoretical performance.

Experimental Results

- Metrics for Evaluation:
  - System configuration:
    - CPU/GPU Cluster
    - GPU Cluster
  - Application parameters:
    - Number of detectors
    - Detector geometry
    - Object geometry
    - Clutter media properties:
      - Particle size
      - Particle type
      - Shape
    - Target object:
      - Number of targets
      - Distance-to-detector array
  - Signal:
    - Frequency: 600 GHz

- Scanning characteristics for larger cluster configurations.

Conclusions

- As a first effort, to the best of our knowledge, terahertz interferometric imaging through cluttered media has been efficiently implemented using a GPU-accelerated cluster.
- The GPU implementation with efficient load balancing outperforms that of CPU implementations in terms of speedup and scalability.
- The experimental results also show that our implementations have favorable scalability features for larger cluster configurations.

References