Towards highly resolved non-mechanical THz imaging using dithering masks with a THz SLM

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Abstract

Emerging THz spatial light modulators (SLM) pave the way to a multitude of advancements in different THz applications, especially high resolution imaging. In some cases, the spatial resolution can be increased even below the wavelength of the employed THz light with less additional measurements than additional gained pixels. Here we present a 345 GHz (0.87 mm wavelength) imaging setting using a computer-controlled THz SLM, a set of specially designed filter-masks and Compressed Sensing based evaluation methods. The THz SLM mainly consists of a SLM for visual light and a 1.5 mm thin disc of semiconducting Germanium, which acts as an optical switch. This optical switch transfers the structure imposed on it with VIS/NIR light to the THz region, thereby being a spatial filter for THz light. The set of specially designed filter-masks are constructed to reduce diffraction effects by using large homogenous pixel blocks while enabling high spatial resolution by shifting the support (dithering) of the pixel blocks on a fine grid.

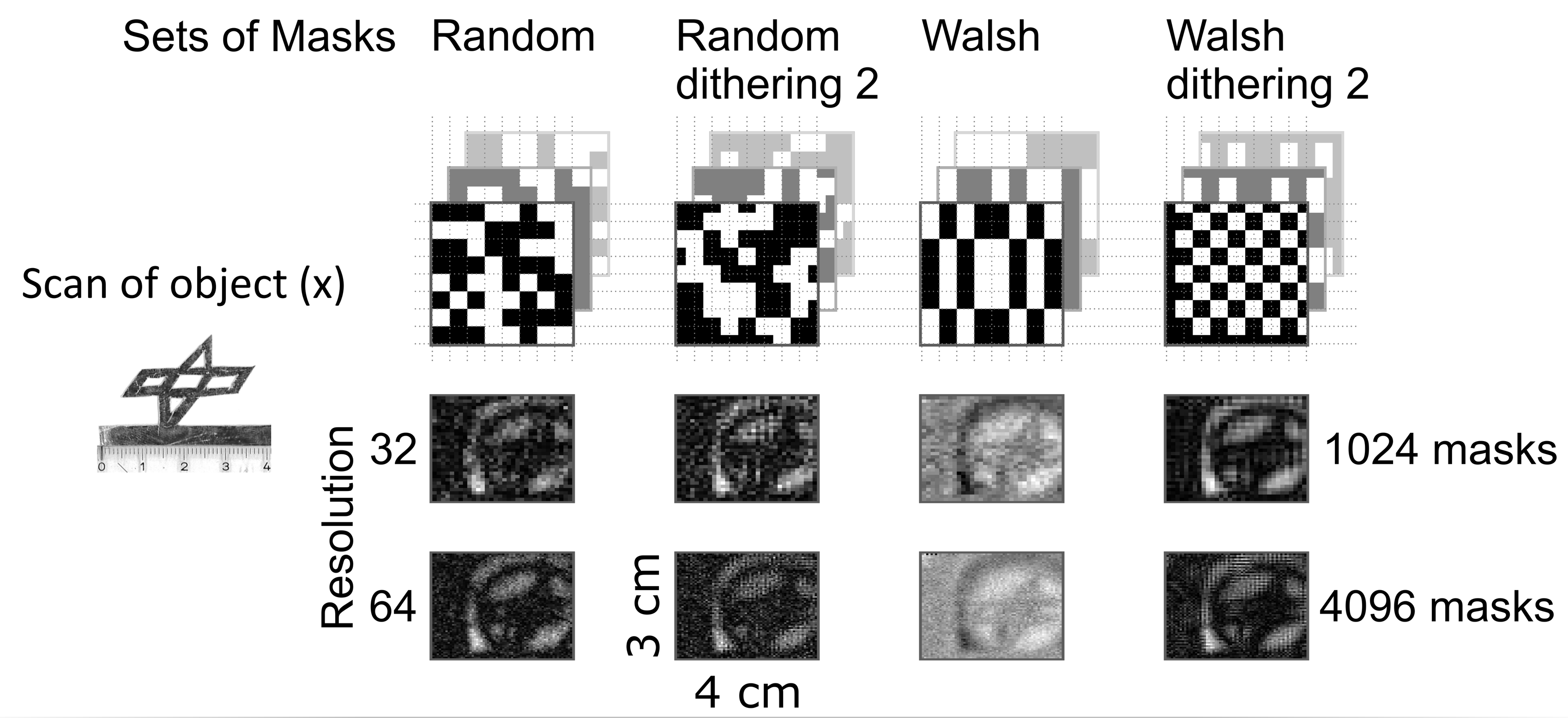
Motivation

- Mechanical scanning limited by moving parts
- THz detector arrays expensive (practically not available)
- THz detectors expensive => use as few as possible
- THz single pixel detector in general more sensitive than a single pixel in an array

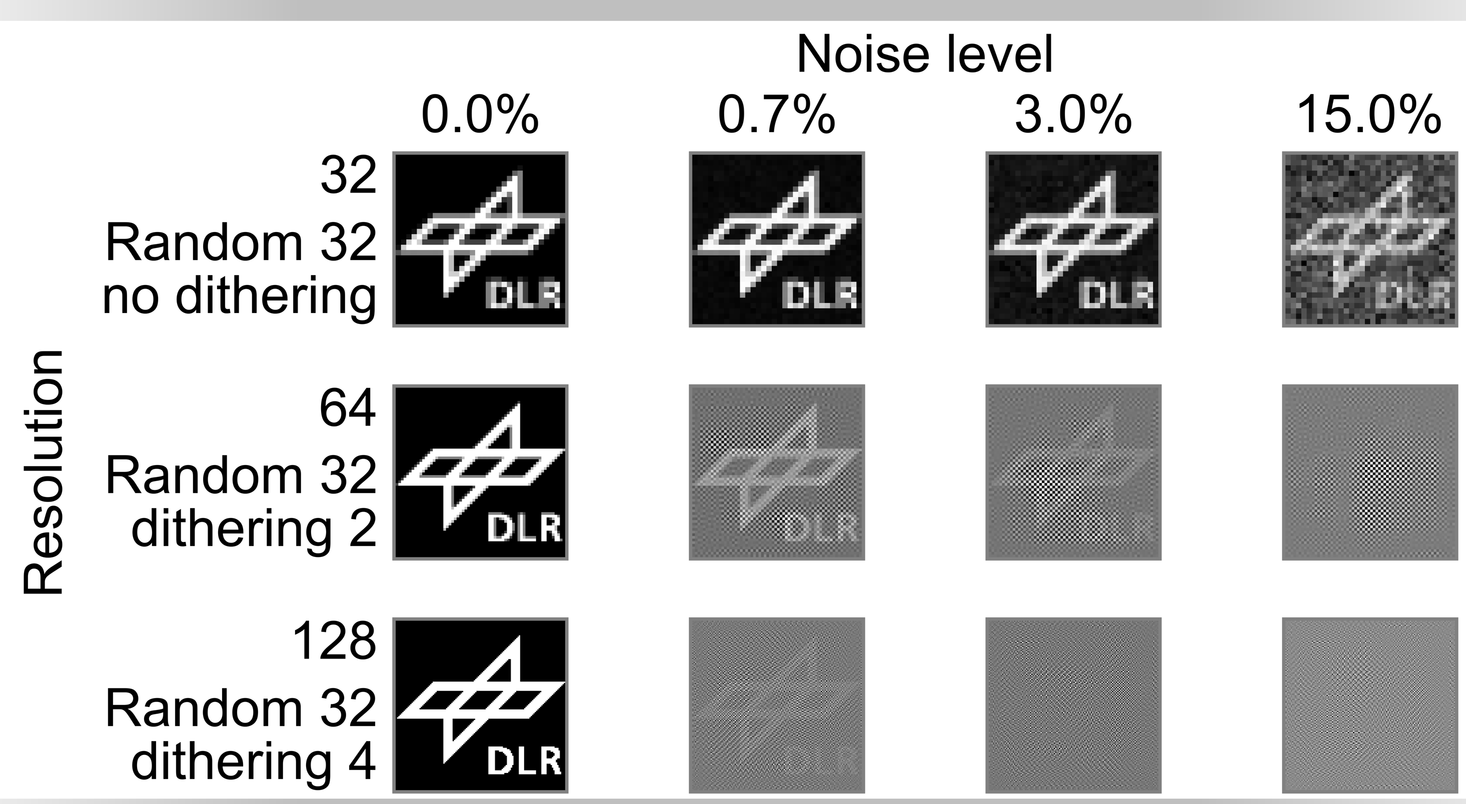
→ THz Imaging using Single Pixel Camera setup

- Imaging resolution limited by wavelength
  - THz: long wavelength (w.r.t. visible light) => more affected

Experimental Results

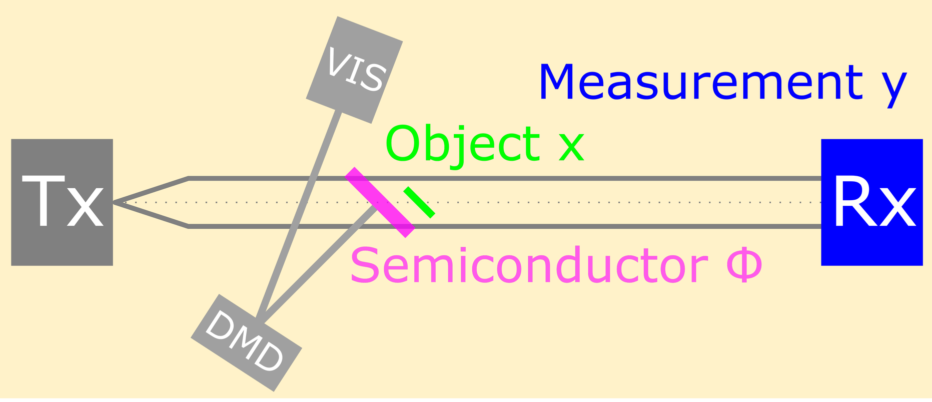


Simulation Results



Experimental Setup

- Single Pixel Camera setup for active imaging at 345 GHz
  - THz Spatial Light Modulator (SLM)
    - VIS-illuminated DMD projects masks onto semiconductor (Ge)
    - Mask element size limited by diffraction => use large mask elements
      - Large mask elements => low image resolution
        → Solution: Use large mask elements and shift them on a grid with a higher resolution (dithering)
    - Several sets of masks (Φ)
      - Standard sets (Walsh/Hadamard, Random)
      - Large (w.r.t. wavelength) mask elements dithering on a finer grid
  - Object (x)
  - Single pixel detector measuring elements of y, one for each mask



Simulation Description

- Binary object (x) representing an image with 128 x 128 pixels is modelled by a vector of length 128*128 = 16384, consisting of zeros and ones
- Set of masks (Φ) (random 32, random 32 dithering 2, random 32 dithering 4) is modelled by a matrix containing one mask in each row of the matrix
- Simulated "measurement values" (y) are calculated by y = Φ * x + white noise
- Simulations are done using different noise levels

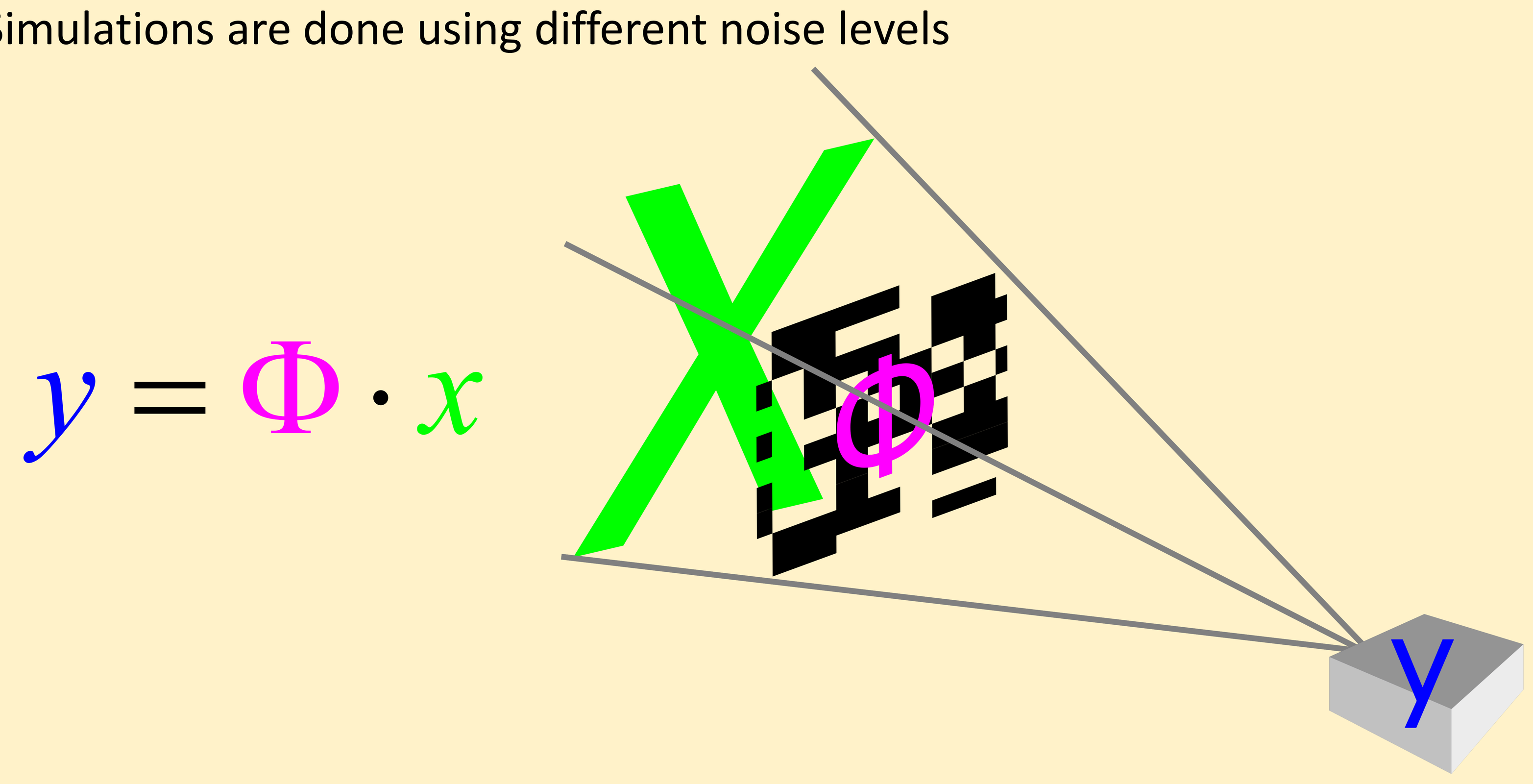
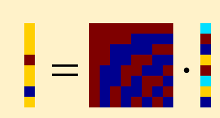


Image Reconstruction

- Image is reconstructed from the known set of masks (Φ) and the obtained measurement values (y) by solving for x the system of linear equation y = Φ * x (+ noise)
- Number of measurements (i.e. the dimension of y) may be less than the dimension of the object (x) to be reconstructed
  - Underdetermined system of linear equations
  - Constraint: Sparsity (Compressed Sensing)
  - Different approaches and algorithms for solving the system



$$\alpha = \Psi^{-1} \cdot x$$
$$\Psi \cdot \alpha = x$$
$$y = \Phi \cdot \Psi \cdot \alpha$$
$$\min_{\hat{\alpha}} \|\hat{\alpha}\|_0 \quad \text{s.t.} \quad \|y - \Phi \cdot \Psi \cdot \hat{\alpha}\|_2 < \varepsilon$$

Outlook

- Hardware Setup
  - Reflecting THz SLM instead of transmitting
  - Collecting optics
  - Investigate diffraction pattern behind THz SLM
- Reconstruction
  - Other algorithms
  - Improved modelling
- Increasing Resolution

Acknowledgement

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