Building a Terahertz 3D single-pixel camera employing a THz-Compressed Sensing Framework

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CoSIP project title: **CS for Terahertz Body Scanners**

- joint project between Technical university Munich
- and Humboldt university Berlin
- collaboration with Technical university Berlin

→ with P. Jung from TU-Berlin (CoSIP-project Bilinear Compressed Sensing)
Introduction

CS for Terahertz Body Scanners  ≡  Building a Terahertz 3D single-pixel camera employing a THz-Compressed Sensing Framework

• Terahertz → more specifically $0.35 \times 10^{12}$ Hertz
• Body Scanner implemented as single-pixel camera
• 3D refers Scanner’s mode of operation → Radar mode
• CS used in a special Terahertz CS Framework
• framework meaning tailored algorithms for CS-based calibration and acquisition schemes

Talk Outline
1. Terahertz (THz)
2. THz - single-pixel cameras
3. Calibration model
4. Image reconstruction
5. Outlook
6. “Take home message”
Terahertz (THz)

- THz-region := 0.1 THz – 10 THz
- region between VIS/IR and radiowave region
- invisible EM-radiation
- so called: quasi-optical region

“quasi” nature causes certain unique challenges in the THz-region
• THz frequency close to the optical region (3.32 THz)

provided by:
M.Sc. Till Hagelschuer - German Aerospace Center (DLR) Berlin-Adlershof
• THz frequency close to the radiowave region (0.35 THz)
Terahertz (THz)

IR

0.35 THz

< 0.0015 Hz
mechanical THz Body Scanner

- multi-pixel cameras are still an emerging technology in the THz-region
- a single-pixel is still very costly (compared to the VIS-region)
- mechanical scanning approaches of moderate number of pixels (slow!!!)
- scanning artifacts and limited resolution
- coherence artifacts worsend by mechanical scanning

novel THz imaging approaches needed
THz – single-pixel cameras

- computational imaging/software scanning with a moderate number of detectors

  idea: build a THz single-pixel camera (THz-SPC)

LITERATURE:


engineering implementation quite challenging
THz – single-pixel cameras

Block Diagram:

- block diagram is the same for every spectral region
- "heart" of every SPC is the spatial light modulator (SLM)
- the higher the capabilities of the SLM the higher is the camera performance (resolution, frame rate, etc.)
Example (Simulation):

Scene + Masks

Reconstruction

Measurement
Measurement Equation: 

\[ y = \Phi \cdot \Psi \cdot \alpha \cdot \chi \]

- \( y \): measurement values
- \( \alpha \): transform coefficients
- \( \Phi \): measurement matrix
- \( \Psi \): transformation matrix (into sparse domain)
- \( \chi \): scene

Things are (a little bit) more complicated in the THz-region. THz-SLMs are not commercially available!!!
THz – single-pixel cameras

Phase II - Setup

1 m

1.5 m

source

THz-SLM

DMD

Halogen-Lamp

Moveable Aperture

Lens - 2

Lens - 1

Attenuator

IT0

RX

detector
THz – single-pixel cameras

THz-SLM:
- cur. 96 x 54 pixel
- max. 1920 x 1080 pixel
- cur. frame rate 0.035 Hz (without CS)
- max. frame rate 0.1 – 0.5 Hz (without CS)

Artifact

Reconstruction

Y, pixel no.
X, pixel no.

calibration model required
FULL calibration model:

- transfer functions $H_i(\cdot)$ influence resolution, image fidelity, imaging speed, etc.
Calibration model

- $H_i(\cdot)$ are not independently measurable
- Focus on the core parts of the THz-SLM

\[
y = p \odot \left( [\Phi; E - \Phi] \cdot \left( b \odot x - a \odot x \right) + n \right) \quad \text{with} \quad u \odot v = \text{diag}(u) \cdot v
\]

- Modulation strongly deviates from ideal value (100%)
- Modulation varies over the field-of-view (FoV)
- Pixel-wise modulation depth

Flat-fielding single-pixel cameras
Calibration model

commanded Mask

THz Mask
Image reconstruction

mask deviations directly influence reconstruction success
Image reconstruction

Data extraction
Image reconstruction

- Phase II THz single-pixel camera (measurement example)
Outlook

- THz imaging interdisciplinary technology/cross-sectional technology security $\rightarrow$ (quantum) electronics $\rightarrow$ medical imaging $\rightarrow$ etc.
- capabilities of an SLM $\rightarrow$ Superresolution, image processing on the hardware level...
- THz CS framework (optimized masks and reconstruction approaches) as well as faster processing
- implement CS reconstruction algorithms on GPUs and/or FPGAs
Terahertz (THz) is invisible EM radiation that penetrates many obstructions but is not harmful to people/living cells when combined with spatial light modulators (SLMs) THz is a useful tool for imaging applications.

The advantages of THz come at a price of certain unique challenges:

- Calibration is needed for imaging fidelity.
- Difference between commanded masks and THz masks makes special THz-mask design necessary for efficient implementation.
- A complete THz CS framework is needed for efficient use of Compressed Sensing in the THz-region.

“We need Theory that matters!”
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THANK YOU for your attention!