News from the Ground Floor

Explorative Imaging at the FleX-Ray Laboratory

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Preamble: Quick introduction to imaging
An inverse problem is

- a problem that fails one or more of Hadamard’s conditions for a well-posed problem:
  1. A solution to the problem must exist;
  2. The solution to the problem must be unique;
  3. The solution depends continuously on the data.

Considering the continuum and discrete CT problems separately…
The continuum case:
Can have a unique solution given the *right data*, but the problem can still be unstable in a reasonable norm, meaning a **severely ill-posed problem**.

The discrete case:
Cannot produce a unique solution due the *finite set of data* yet with *infinite number of unknowns*, but it can be stable and therefore **mildly ill-conditioned**.

Small changes in the measured data can lead to big changes in the reconstructed image.
PART I

3D illustration of a simple apparatus set up for cone beam.

3D illustration of a simple apparatus set up for cone beam.
The CT problem explained

2D (xz-)view of a single ray from a point source with the intensities $I_0$ at the source and $I$ at the detector.

Source | Object | Detector

Rays leave with intensity, $I_0$  
Rays arrive with intensity, $I$
Consider a single point, $dx_L$ on a monochromatic X-ray beam...

$L(x)$, the length of the X-ray beam travelling through the object, $dI$ the intensity value at the point $dx_L$.

At this point $dx_L$, the beam has lost some intensity proportional to its initial intensity, $I_0$,

$$dI = -\mu(x)I_0dx_L.$$

Here, $\mu(x)$ is the attenuation coefficient, i.e. the rate at which the photons are absorbed (or scattered).
This implies

\[ I = I_0 e^{-\int_L(x) \mu(x) \, dx_L}. \]

In physical terms, this describes that the monochromatic beam is **attenuated exponentially** as it travels through an object.

This is commonly referred to as the **Beer-Lambert Law**.
Monochromatic beam is

- an X-ray beam with a single energy (also referred to as a white beam),
- expensive to produce
- need synchrotrons
- not available in a laboratory setting!

Therefore we have to consider X-rays with multiple energies, i.e. **polychromatic beams**.
Since we now depend on varying energy levels as well as the location in the object, the CT model becomes

\[ I = \int_{L(x)} I_0(E) e^{-\int_{L(x)} \mu(x,E) dx L} dE. \]

Initial intensity of beam now depends on energy of the beam as it leaves the source.

Integrating over all energy levels

Attenuation of an object also depends on the energy of beam at that location.
Since we now depend on varying energy levels as well as the location in the object, the CT model becomes

$$I = \int_{L(x)} I_0(E) e^{-\int_{L(x)} \mu(x,E) \, dx} \, dx \, dE.$$ 

Mathematically, the goal is to recover the attenuation coefficient from the information at detectors.
Explorative imaging in a flexible setting
Explorative Imaging

Sequential

Dynamic

Scanner

Scanner

Data Acquisition

Reconstruction & Visualisation

Research Analysis

Data Acquisition

Reconstruction & Visualisation

User Feedback
Explorative Imaging
Explorative Imaging

Acquisition

Scanner

User Feedback

Reconstruction & Analysis

Server Room

Recast3D
Explorative Imaging

Diagram showing the process of explorative imaging:
- **Acquisition** feeds data into a **Scanner**, which then sends it to **Reconstruction & Analysis**.
- **Reconstruction & Analysis** sends 10Gb of data to the **Server Room** and also receives 10Gb of data from the **Scanner**.
- The **Server Room** feeds data into a **Recast3D** computer, which in turn sends data back to **User Feedback**.

The diagram illustrates a cycle of data flow and analysis in the context of explorative imaging.
Explorative Imaging
The FleX-Ray Laboratory
Introducing FleX-Ray Laboratory

Ten programmable motors in the full flexible setup.
Introducing FleX-Ray Laboratory

Real-time data streaming and almost-instantaneous reconstructions.
Introducing FleX-Ray Laboratory

Ability to incorporate additional components: Spectral detector.
Motors

Source

Sample Stage

Detector

Vertical (Source)
Transversal (Source)
Vertical (Piezo)
Horizontal (Piezo)
Transversal (Sample)
Horizontal (Sample)
Rotational (Sample)

Vertical (Detector)
Horizontal (Detector)
Transversal (Detector)
Motors

Circular

Helical
Motors

Zoom in

Tile in detector plane
Motors
Latest imaging news from the ground floor
Recovering the name of an author
The dating of chapters and the consistent handwriting suggests a single author, produced between 1661 and 1664.

18 signatures, all crossed out.
Problem Description

Two different iron gall inks. Differing chemical compositions: second is from late 18th to early 20th century.

Original ink contains more metal, coincides with the usage in 17th century.
Uncovering writings in old manuscripts is done using X-ray florescence or phase contrast in synchrotrons.

In contrast we have two layers of ink, and a laboratory X-ray absorption imaging...
Can we recover the name of the author?
Experimental Plan

Only allowed to move the tube and detector up/down or sideways.
Experimental Plan
Action Plan

Due to sample fragility, take 2D radiographs of 18 locations.

Collect high quality radiographs at various energy levels and exposure.

Automate the image processing, extract information from processed radiographs.

Correlate corresponding letters to recover full name of author.

A fun inverse problem in itself: Relies heavily on quality of input data...
False positives?
Lea or Lee
Lea or Lee
Cor or Coe

Leendert Cornelisse Romeijn
The national archives contain a certain individual with the name Leendert Romeijn. Leendert lived in Rotterdam and had 6 children. One of his sons was named Cornelis Romeijn!

Leendert was a trader.
Expert feedback invaluable.
Could automation have been viable in the absence of expert feedback?
Could a machine learn to rule out a false positive?
Adapting geometry during acquisition
Experimental Setup

Tablet is placed at the bottom of a clear cylindrical plastic container. Gel decanted prior to data acquisition.

Rotation is 200 deg/s with 150 projections per 360 degrees with 12ms per projection: a total of 166 rotations, i.e. 5 minutes acquisition time.

Each projection is binned but not cropped, (size 487px x 385px). The spatial resolution at the beginning of the experiment is 193μm, at the zoom it is 76μm.

Action camera mounted on top of the source, tilted downwards to capture the entire setup.
Results
Towards a smarter future?
The future of CT acquisition experiments

What can we teach the system?

Can we teach the system to make simple decisions?

Can we teach the system to make difficult decisions?

Should AI be involved fully in the process and operator made redundant?
References

Thank you for your attention!


Computational Imaging -- Centrum Wiskunde & Informatica

Recent uploads

RECAST3D
Buurlage, Jan-Willem; Palenstijn, Willem Jan; Hendriksen, Allard; Pelt, Daan; Graas, Adriaan; Kohr, Holger;
Full-stack implementation of a real-time tomographic reconstruction and visualization pipeline. Source code.
Documentation
Uploaded on April 28, 2020

High-resolution cone-beam scan of twenty-one walnuts with two dosage levels
Lagerwerf, Marinus Jan; Coban, Sophia Bethany; Batenburg, K. Joost;
We release tomographic scans of 21 walnuts with two levels of radiation dosage for noise-level comparative studies in
data analysis, reconstruction or segmentation methods. The dataset collected with higher dosage is referred to as the
"good" dataset, and the other as the "h
Uploaded on April 23, 2020

A five-tile tomographic micro-CT dataset of the oak sculpture "Holy woman with lantern" - part 2 of 2
Francien G. Bosserma; Alexander Kostenko; Sophia Bethany Coban;
Uploaded on April 10, 2020

https://zenodo.org/communities/ci-cwi/