Spectral Computed Tomography Based on Semi-monochromatic Imaging

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Introduction

Spectral computed tomography (CT) improves conventional imaging by analyzing how materials absorb X-rays at different energies. This enables precise **material differentiation**, reduces **beam hardening artifacts**, and allows for **quantitative imaging**.

Most spectral CT systems rely on either:

- **spectral detectors** (photon-counting or dual-layer) to differentiate X-ray energies after detection,
- **energy-tuned X-ray sources** to shape the spectrum before detection.

The **Rigaku nano3DX** system takes the latter approach. Using a **dual-material target (Cu, Mo)** and optimized filtration, it generates a **semi-monochromatic spectrum** dominated by **characteristic radiation (K_α or K_β).**

Rigaku nano3DX

This method provides:

- **high contrast for soft materials**,
- **accurate extraction of linear attenuation coefficients (LAC)**,
- **simplified material analysis without detector calibration**.

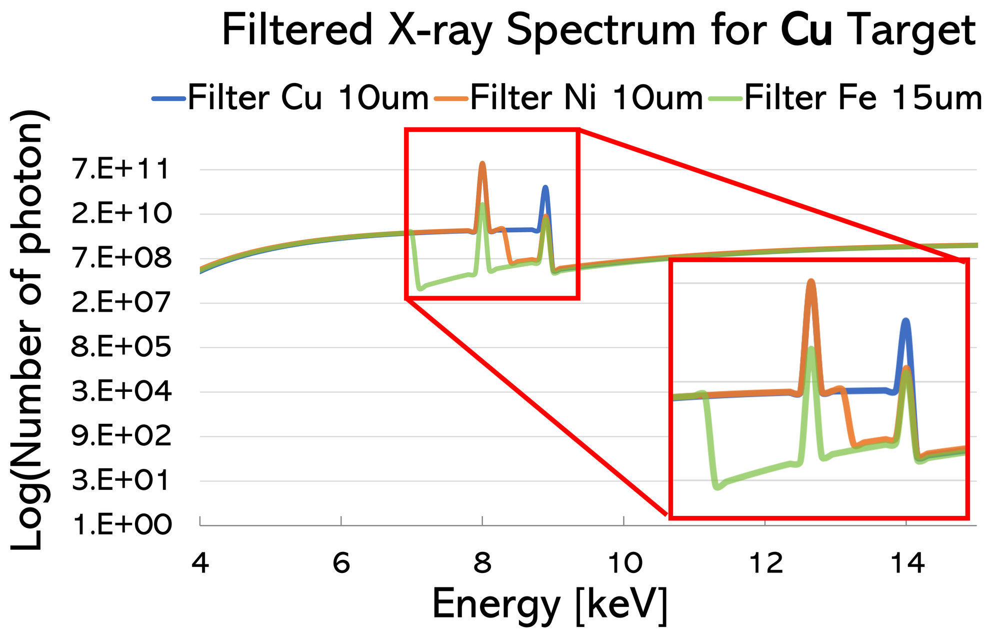
By controlling the X-ray spectrum at the source, nano3DX **eliminates the need for complex spectral detectors**, making it a powerful tool for material characterization.

Feature	Spectral CT	Rigaku nano3DX
Spectral separation	After detection	At the source
Beam hardening	Requires correction algorithms	Naturally minimized
Material differentiation	Requires spectral binning	Direct LAC extraction
Detector efficiency	Must be calibrated	Not relevant
Best suited for	Multi-Material discrimination	Imaging soft materials

Materials & Methods

X-ray Spectrum Filtering

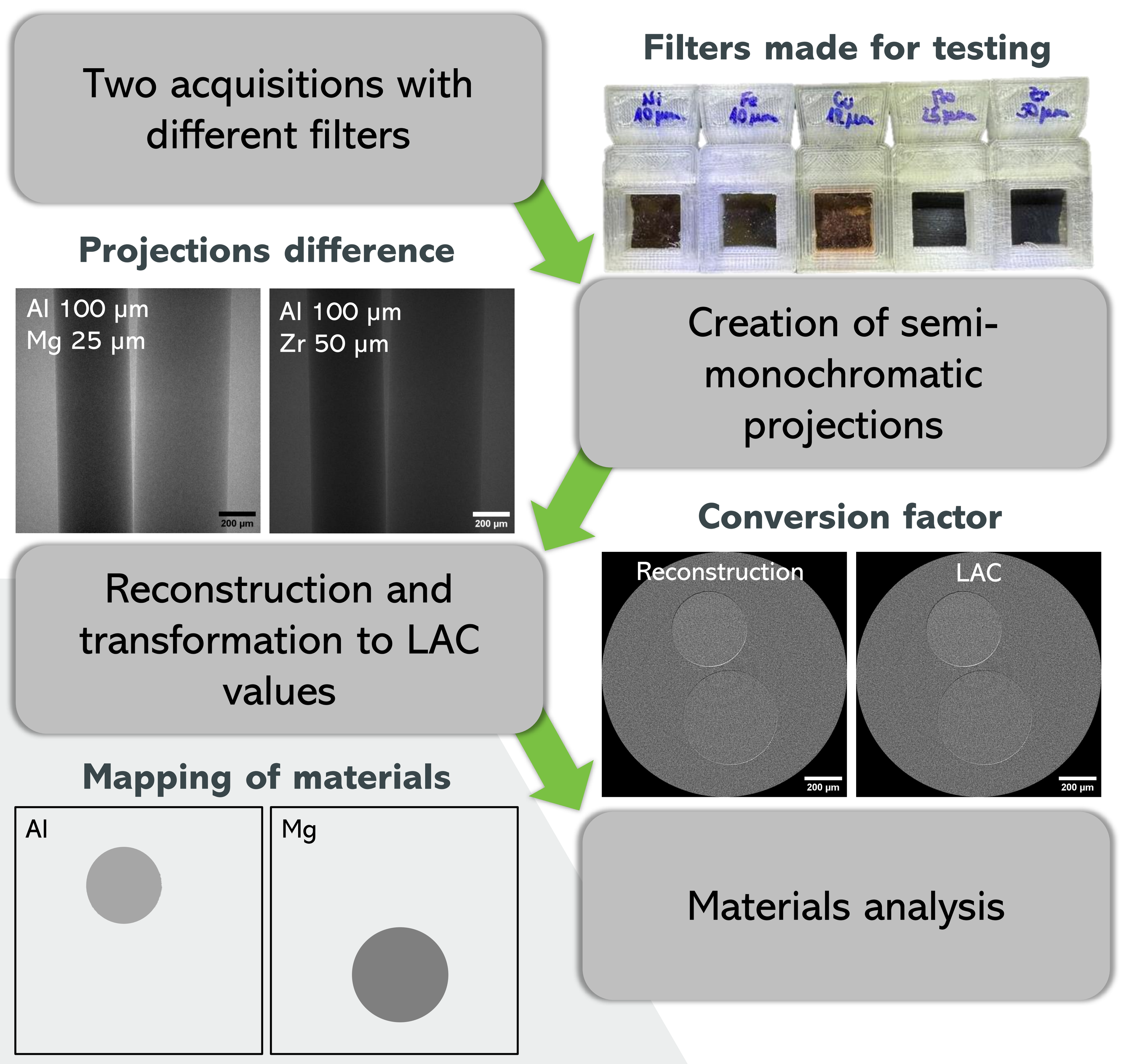
Filtration in nano3DX is a **highly efficient and straightforward process**, relying on thin foils with thicknesses in the range of tens of micrometers. **Materials** such as **Fe, Ni, Cu, Zr,** and **Mo** have been shown to be **effective** in **filtering** specific spectral segments. Additionally, the use of **layered filters** has proven to be particularly advantageous, as it **enhances the concentration of photons** around the desired characteristic edges. A notable example of this approach is the combination of Al with Mo and Zr filters, which allows for more precise spectral shaping and improved control over the transmitted photon energies.



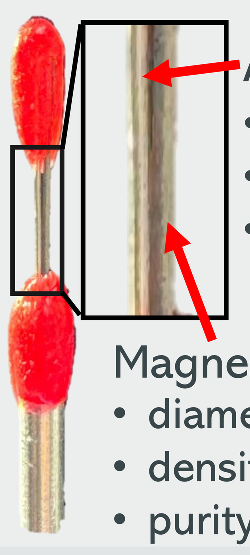
Material options for filters with Cu and Mo targets, indicating which part of the X-ray spectrum they transmit. White means bremsstrahlung is transmitted. K_α and K_β imaging require appropriate filter pairs.

Target	White	K_α + White	K_α + K_β + White
Cu	Fe (Co)	Ni	Cu
Mo	Y (Y_2O_3)	Zr (Nb)	Mo
	K_α imaging	K_α imaging	
		K_β imaging	K_β imaging

Semi-monochromatic Imaging



Acquisition Design



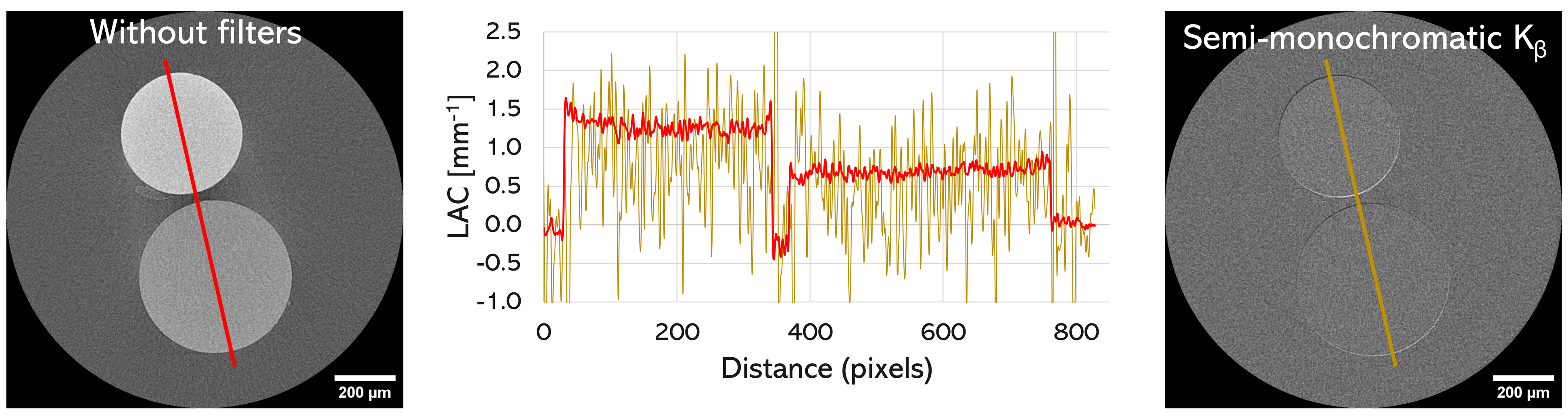
Aluminium
- diameter: 40 µm
- density: 2.7 g/cm³
- purity: 99.9 %

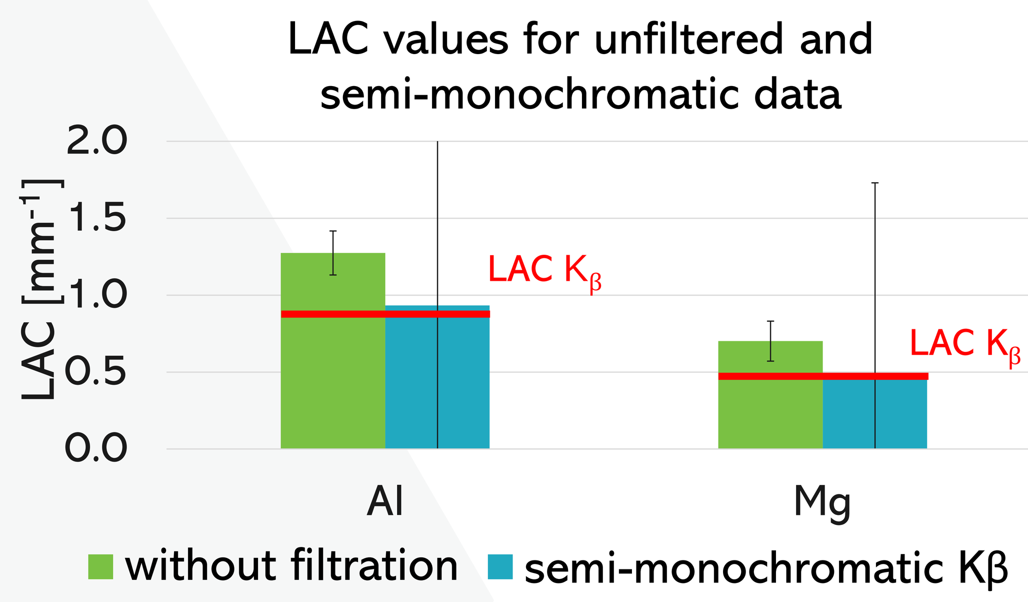
Magnesium
- diameter: 50 µm
- density: 1.738 g/cm³
- purity: 99.95 %

Parameter	Value
Target	Mo, 50 kV/24 mA
Scan time	15 min
Filter 1	Al 100 µm Mo 25 µm
Filter 2	Al 100 µm Zr 50 µm

Results & Discussion

The measurements were centred on the semi-monochromatic K_β radiation from the Mo target. Despite the similarity in LAC values exhibited by Al and Mg, a distinction between them can be made with a reasonable degree of accuracy. The ensuing bar graph illustrates the theoretical values of the LAC for X-rays in the materials making up the phantom at the energy of Mo K_β radiation. It is evident that, in the absence of filtration, the LAC values exceed this benchmark. The suppression of beam hardening artifacts was effective, reducing the distortion of the reconstructed images without the use of additional algorithms. However, it should be noted that the noise in the resulting data increased by several orders of magnitude, a phenomenon that can be attributed primarily to the subtraction of projections obtained with different filters, given their divergent noise characteristics and also decrease in the baseline signal value in the subtracted data. It is imperative to note that the measurements are performed sequentially, i.e. successively for each filter. During this process, the sample may move if it is not well stabilized, as was observed in this case.





The further research will focus on efficient denoising of data, utilising the methodology of the diffusion partial differential equation. Special emphasis will be placed on sample preparation and stabilization or algorithm development to avoid or correct for motion artifacts. Practical experiments will mainly focus on differentiating lightweight materials that are difficult to analyze using other spectral CT methods.

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