POLYCHROMATIC ITERATIVE RECONSTRUCTION ALGORITHM FOR DIRECT RECONSTRUCTION OF DENSITY INFORMATION IN X-RAY CT

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Summary: A method is presented to reconstruct quantitative material densities from X-ray CT data instead of reconstructing a linear attenuation coefficient in each voxel of the 3D volume. The polychromatic behavior of the complete system is included in the reconstruction method, as such calibration materials are not required and beam hardening artefacts are inherently eliminated from the reconstructed data.

1. INTRODUCTION

In high-resolution laboratory-based micro-CT sample size, composition and instrumentation used can vary drastically between different applications. Therefore, standard scanning protocols (scan settings) are almost non-existent. Consequently, standard techniques for material characterization such as the Hounsfield scale [1] or dual-energy CT [2,3] which depend on these protocols are difficult to use.

A POLYchromatic Simultaneous Algebraic Reconstruction Technique (POLYSART) is developed which is able to characterize the density in each voxel of a three dimensional volume. This is done by taking into account the complete spectral behavior of the X-ray CT system, based on the polychromatic simulation tool [4] developed at the Centre for X-ray Imaging of Ghent University (UGCT). By incorporating the complete spectral behavior in the reconstruction of the CT data, a correction is inherently performed for all artefacts caused by the spectral behavior of the systems known as beam hardening artefacts. Moreover, the output data no longer depend on the acquisition settings but contain quantitative material densities.

2. EXPERIMENTAL METHOD

The proposed method takes advantage of a physical model of the X-ray CT system, which describes the spectral behavior of the entire setup rather than only that of the sample or X-ray tube. The simulated transmission T_S of a polychromatic beam through a sample is given by

$$T_S = \frac{I}{I_0} = \frac{\int_0^{E_{max}} S(E)D(E)\exp\left(-\frac{\mu}{\rho}(E)_{air}\,\rho_{air}d_{air}\right)\exp\left(-\int_L \frac{\mu}{\rho}(E,l)\,\rho(l)dl\right)}{\int_0^{E_{max}} S(E)D(E)\exp\left(-\frac{\mu}{\rho}(E)_{air}\,\rho_{air}d_{air}\right)} \quad (1)$$

in which E is the photon energy and $S(E)$ and $D(E)$ are the source spectrum and detector spectral response, respectively, in which beam filtration can be included. Furthermore $\mu/\rho(E)$ is the mass attenuation coefficient, ρ the density and L the path length trough the sample.
The updated reconstructed density in the j^{th} voxel can then be calculated by

$$\rho_j^{(v+1)} = \rho_j^{(v)} + \lambda\,\frac{C_i}{L_i\,\frac{\overline{\mu}}{\rho}}. \quad (2)$$

Here L_i is the length of the ray through the sample projected in the i^{th} pixel, $\overline{\mu/\rho}$ an approximation of the average mass attenuation coefficient and λ a relaxation parameter. The correction term C_i is calculated from the logarithmic difference of the measured and simulated transmission.

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3. RESULTS

A sample typically used in wood densitometry was scanned at the HECTOR [5] system at UGCT. The CT data was reconstructed using a conventional SART algorithm and the POLYSART algorithm (Figure 1). Although qualitatively, both images are of the same level, a quantative difference in the reconstruction can be seen clearly. An estimated density of 1.481 ± 0.026 g/cm³ of the POM was found, which is within the range of the real density of POM (1.40 – 1.42 g/cm³).
Furthermore, during the presentation, a method will be proposed to apply the POLYSART method on data containing multiple materials with non-uniform chemical composition.

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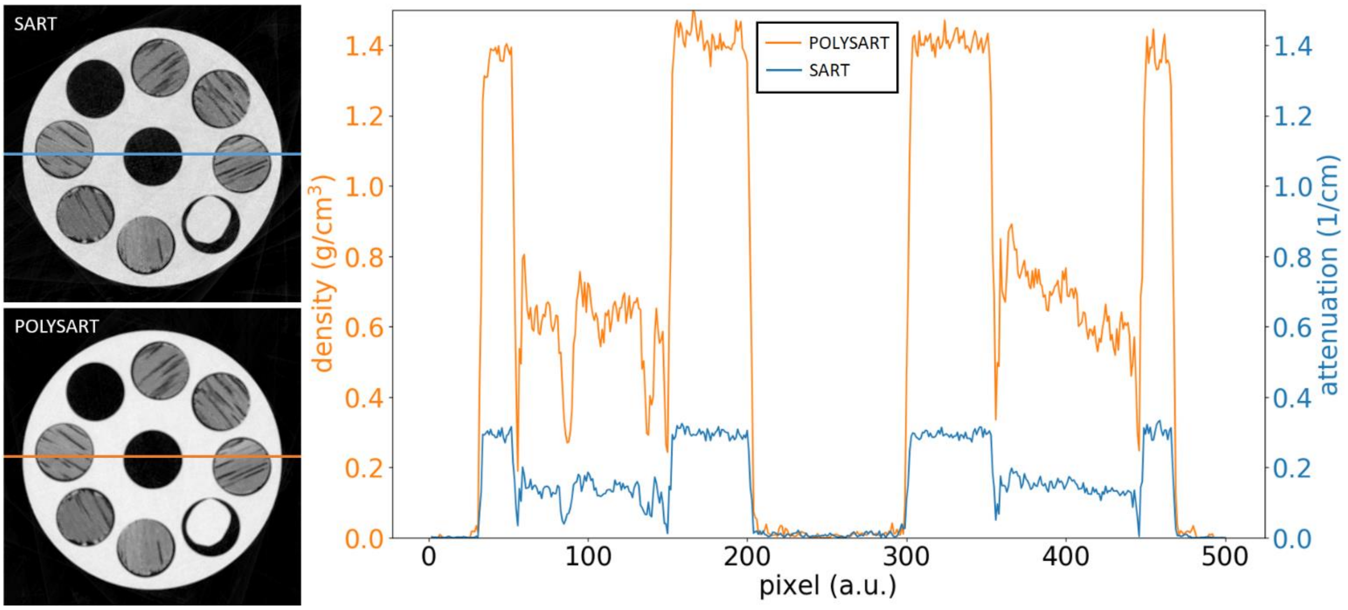

Figure 1: An example of the developed technique for performing calibration free densitometry. The sample consist of wood pieces placed in a Polyoxymethylene (POM) cylindrical holder. The reconstruction of a conventional SART algorithm (blue) is compared with the polychromatic algorithm reconstructing a density parameter (orange) in each voxel. A reconstructed density for the POM was found of 1.418 ± 0.026 g/cm³ which is within the range of the real density of POM (1.40 – 1.42 g/cm³).