Quantitative material decomposition method for spectral CT imaging

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Abstract

Spectral CT is a promising new imaging modality that is able to provide spectral information of several pre-selected energy ranges in one image acquisition, which allows quantitative decomposition of multiple materials. In addition to conventional reconstruction, novel decomposition techniques should be developed to realize material separation. Decomposition of multi-energy X-ray data into basis materials can be performed in the projection domain, image domain, or during image reconstruction. In this work, a projection domain decomposition method was introduced and accomplished by a simulated phantom study. Its performance is evaluated not only for heavy atoms with their individual K-edge signature like gadolinium and iodine, but also for lighter atoms like iron, calcium and potassium. It is shown that this approach succeeds in the quantification of gadolinium, iodine and iron, moreover, it is also capable to discriminate iron and potassium from water and PMMA.

Keywords: material decomposition, Spectral CT, K-edge, X-ray

1 Introduction of material decomposition method

X-ray computed tomography (X-ray CT) has become a common medical imaging modality since its introduction in the 1970s. Making use of variable attenuation coefficients of X-rays by different tissues, it achieves to provide a 2-dimensional projection image of the tissues within the patient's body. However, conventional X-ray CT system gives integrated attenuated energy of the whole spectrum which leads to inadequate information to identify different materials. Spectral X-ray CT has the ability to correct this deficiency. With photon counting detectors, it is able to provide spectral information of several pre-selected energy ranges in one image acquisition, and has the potential to significantly improve X-ray CT by reducing dose, enable K-edge imaging using high-Z contrast agents such as gadolinium and iodine and provide quantitative material decomposition [1-3].

Decomposition of multi-energy X-ray data into basis components can be performed in the projection domain, image domain, or during image reconstruction. In the method proposed by J. P. Schomlka, E. Roessl et al. for K-edge imaging [1], the idea is to decompose the linear attenuation coefficient into a basis of known materials. It is considered that the linear attenuation coefficient can be approximated by a linear combination of the photoelectric effect, Compton effect and extended K-edge components [4] when there are materials with their K-edge within the CT energy range.

In the present work, a projection domain decomposition method was introduced and accomplished by a simulated phantom study. The linear attenuation coefficient \( \mu \) is described by the linear combination of the mass attenuation coefficients \( \mu_m \) weighted by the density \( \rho \) of different materials with priori known. The types of materials chosen for the decomposition depend on the objective under investigation and the prior knowledge of the scanned objects. Based on this formulation of the direct problem, an objective function for minimization is then defined to estimate the line integrals of \( \rho \) for each projection data and then an independent reconstruction is followed to get density distributions of each material. The proposed method is compared with the K-edge imaging method of [1].

2 Description of spectral CT imaging system

A spectral CT system that has 6 energy-bin (20-30, 30-40, 40-50, 50-60, 60-70 and 70-80 keV) resolving capability is simulated by INSRA software Virtual X-ray imaging (VXI) [5]. Two PMMA phantoms were built for scanning, one with “K-edge materials”, denoted “K-edge phantom” in the following, while the other one with low-Z materials that lack prominent K-edges within our energy range, and denoted “non-K-edge phantom”. As shown in figures 1 (left) and 2 (left), the insert materials diluted by water were labelled by left side with noted densities in mg/cc. Note that the sign * stands for mixture inserts which contain all three materials with the corresponding concentration noted for inserts right below them.

3 Results and analysis

Figure 1 shows the decomposition results obtained with the K-edge imaging method of [1] and our proposed method. It is observed that both succeeded in quantitative discrimination of gadolinium and iodine. However, in the case of iron, the method...
of [1] did not identify iron as such, because iron has no K-edge in the energy range, and thus, its attenuation is included in the decomposition through photoelectric effect and Compton effect (in figure 1 (middle), iron is visible in the photoelectric image). On the contrary, with our method, as iron is included as such in the materials basis, we get a quantitative image of its concentration. Figure 2 illustrates decomposition results of the non-K-edge phantom, where the three basis materials chosen are PMMA, iron and potassium. From figure 2 (middle), we can see that PMMA and water are in the top first image, iron is separated in the top second one with the concentrations agreeing well with true values. Potassium and calcium are mixed together in the bottom image, with the potassium densities of pure potassium inserts quite accurately measured but the densities of the mixture inserts being about two times the true value since calcium has also been classified into potassium basis. The problem of weak distinction between calcium and potassium is caused by their close Z number and similar densities.

The results show that the proposed method is quite promising since it presents the advantage of being suitable for both non-K-edge material quantification and K-edge materials. Further development would be focused on the discrimination of materials with similar attenuation properties, to apply the proposed method to real spectral CT data, and to evaluate its robustness to noise.

![Scheme of the K-edge phantom](image1.png)

Figure 1. Scheme of the K-edge phantom (left). Decomposition results of K-edge imaging method of [1] (middle) and our proposed method (right) for the K-edge phantom.

![Scheme of the non-K-edge phantom](image2.png)

Figure 2. Scheme of the non-K-edge phantom (left). Decomposition results of our proposed method (middle) on the “non-K-edge” phantom. Measured material densities of pixels along the center line of insert rows (right): green line represents the theoretical values, blue line pure the material inserts and red line the mixture inserts.

References


