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Feasibility of basis material decomposition with multilayer detectors

Dong Woon Kim [a], Ho Kyung Kim [a,b*]
[a] *School of Mechanical Engineering, Pusan National University, Busan, Republic of Korea*
[b] *Center for Advanced Medical Engineering Research, Pusan National University, Busan, Republic of Korea*
[*] *Corresponding author: hokyung@pusan.ac.kr*

1. Introduction

In the diagnosis of lesions using x-ray imaging, it is important to identify the presence or absence of the lesion, and to distinguish between the surrounding background and the lesion. The dual-energy imaging has been extensively studied as a technique for distinction of lesions by suppressing anatomical background [1, 2]. However, dual-energy imaging can result in motion artifacts due to two exposures. In this regard, a single-shot dual-energy imaging using a sandwich detector is proposed to compensate for motion artifacts [3, 4].

The basis material decomposition is a technique for describing the linear attenuation coefficient of an arbitrary material using the linear attenuation coefficients of the basis materials [5, 6, 7]. An arbitrary material can be expressed as a linear combination of known basis material information. By applying this, only the bone or tissue information can be extracted from the image.

In this study, we implement the material decomposition algorithm and apply it to a sandwich detector to perform a feasibility study of a single-shot dual-energy imaging. We have confirmed the possibility using Monte Carlo simulation and will validate to use the experiment.

2. Theoretical background

2.1 Basis function

The basis function introduced by Alvarez and Macovski describes the linear attenuation coefficient $\mu_\xi(E)$ for material ξ at energy E as weighting sum of photoelectric absorption and Compton scattering [5]. Lehmann also described an arbitrary $\mu_\xi(E)$ using $f(E)$ of two basis materials [6], which can be expressed as:

$$\mu_\xi(E) = A_1 f_1(E) + A_2 f_2(E), \quad (1)$$

where, A is the thickness of material and $f(E)$ is the basis function.

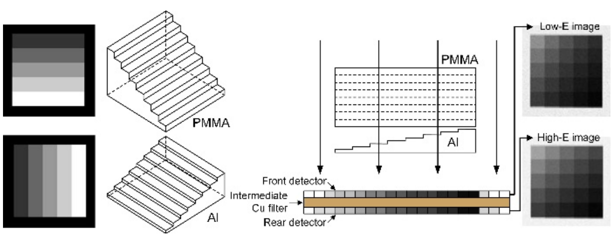

Fig. 1. Sketch describing step-wedge phantoms of Al and PMMA and a schematic showing x-ray projections

Signal of energy-integration detector is obtained by integrating the energy information that passes through the object from the incident x-ray spectrum $\Phi(E)$. The signal obtained from the detector through a certain material can be described using two basis materials as follows:

$$I(A_1, A_2) = \int \Phi(E) e^{-A_1 f_1(E) - A_2 f_2(E)} R(E) \mathrm{d}E, \quad (3)$$

where, $R(E)$ is detector response.

2.1 Material decomposition algorithm

Since the detector signal of Eq. (3) described by two basis materials is a nonlinear integral equation, it is difficult to extract only information about A_1 and A_2. In order to solve the nonlinear integral equation, we describe it as a quadratic function using the logarithm detector signal.

$$P^j(A_1, A_2) = b_0^j + b_1^j A_1 + b_2^j A_2 + b_3^j A_1^2 + b_4^j A_2^2 + b_5^j A_1 A_2 \quad (4)$$

where, j denotes low or high energy and b denotes least-squares regression parameter. A two basis material combination is used to create a regression map, which is used to extract the basis material. A material decomposition image can be acquired by estimating an arbitrary image pixel value using the Gauss-Newton method.

$$x_{n+1} = x_n - \left[P^L(x_n, y_n)\frac{\partial P^H}{\partial y} - P^H(x_n, y_n)\frac{\partial P^L}{\partial y}\right]/J \quad (5)$$

$$y_{n+1} = y_n - \left[P^L(x_n, y_n)\frac{\partial P^H}{\partial x} - P^H(x_n, y_n)\frac{\partial P^L}{\partial x}\right]/J \quad (6)$$

where x and y denote the thickness of the basis material to be obtained, respectively, $J = \frac{\partial P^L}{\partial x}\frac{\partial P^H}{\partial y} - \frac{\partial P^L}{\partial y}\frac{\partial P^H}{\partial x}$.

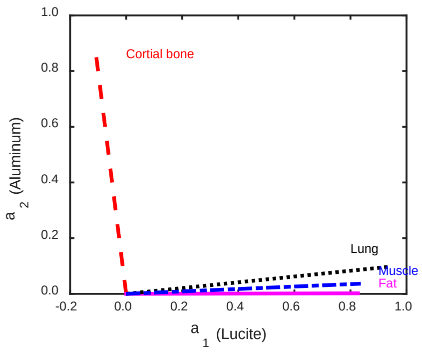

Fig. 2. The basis material plane of body structure memetic material into thicknesses of Lucite and aluminum.

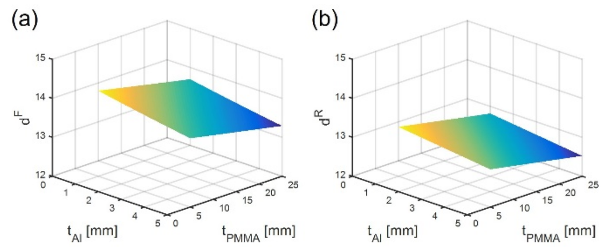

Fig. 3. Signal of the sandwich detector changes due to Al and PMMA thickness variations. (a) Front detector signal and (b) rear detector signal.

3. Materials & Methods

3.1 Monte Carlo simulation

Figure 1 is a sketch describing the step-wedge phantoms and a schematic showing x-ray projections. The steps of two step-wedge phantoms composed of aluminum (Al) and poly-methyl methacrylate (PMMA) are 1 mm and 5 mm, respectively. The maximum thicknesses of Al and PMMA step-wedge phantoms are 5 mm and 25 mm, respectively. The step-wedge phantoms are positioned to rotate 90 degrees to obtain image signals of various thickness combinations. The x-rays passing through the step-wedge phantoms is measured the signal at the sandwich detector and the rear detector of the sandwich detector measures the relatively high-energy signal passing through the front detector and the intermediate filter.

4. Preliminary results

Figure 2 shows the basis material plane of body structure mimetic material into thicknesses of Lucite and aluminum using Eq. (1). Body structure materials such as cortical bone, muscle, lung tissue, and fat are described two basis materials.

The quadratic function of Eq. (4) is applied to the image obtained by the Monte Carlo simulation shown in Fig. 1. The simulation images are obtained with 90 kVp and 0.5 mm-Cu intermediate filter thickness. Figure 3 shows the sandwich detector signal as a function of Al and PMMA thicknesses obtained using least-square regression. It can be seen that the signal decreases with increasing Al and PMMA thicknesses, and it can be confirmed that it is linearly regressed according to the combination of thickness. Figure 4 shows the Al and PMMA images obtained using material decomposition algorithm in dual-shot (60 kVp / 90 kVp) and single-shot (90 kVp) conditions. The material decomposition image using single shot shows a little more noise than the material decomposition image using dual shot. However, it can be seen that Al and PMMA are well separated from the phantom in which Al and PMMA are superimposed.

5. Ongoing and Further Studies

In a further study, we will conduct experiments with the sandwich detector and calculate the material decomposition results and errors. In addition, we will apply to the mouse-mimetic phantom to acquire images that separate bone tissue and soft tissue using the material decomposition algorithm.

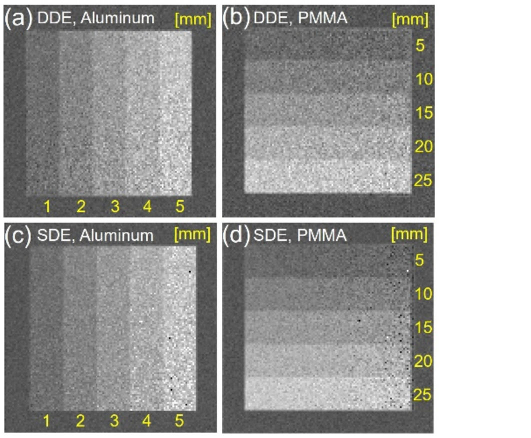

Fig. 4. Al and PMMA distinction result using material decomposition algorithm in dual-shot (60 kVp / 90 kVp) and single-shot (90 kVp) conditions. (a) Al and (b) PMMA using dual shot, (c) Al and (d) PMMA using single shot.

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