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RADIATION IMAGING LABORATORY

Feasibility of basis material decomposition with multilayer detectors

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Dong Woon Kim, Ho Kyung Kim

Radiation Imaging Laboratory,
School of Mechanical Engineering
Pusan National University, Republic of Korea

Outline

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- Theoretical background
  - Basis function
  - Material decomposition algorithm
- Materials & Methods
- Results
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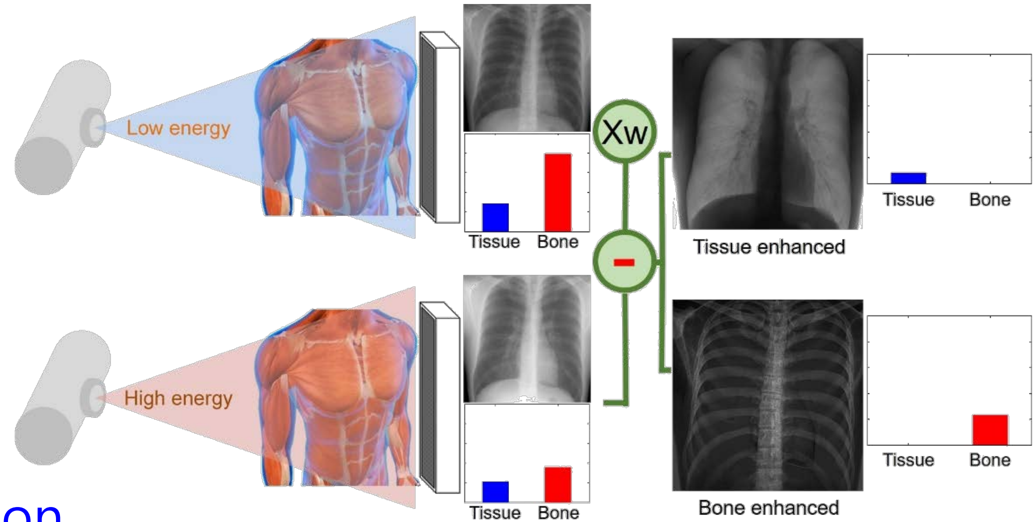
Radiation Imaging Laboratory,
Pusan National University
Dong Woon Kim {dongwoonkim@pusan.ac.kr}

Dual-energy imaging

- The dual-energy (DE) imaging increases the conspicuity and allows a better view of the lesion to be seen
- Two approaches
  - Energy subtraction

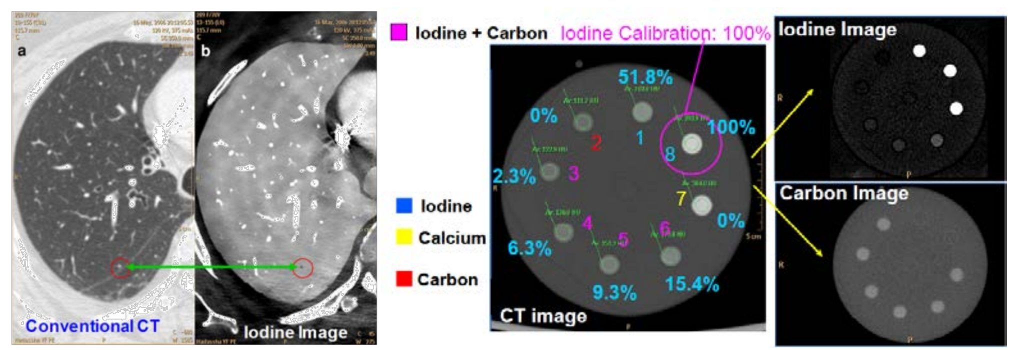
    weighted subtraction of images taken at two different energies



E. Shefer et al., *Curr. Radiol. Rep.* (2013)

  - Basis material decomposition

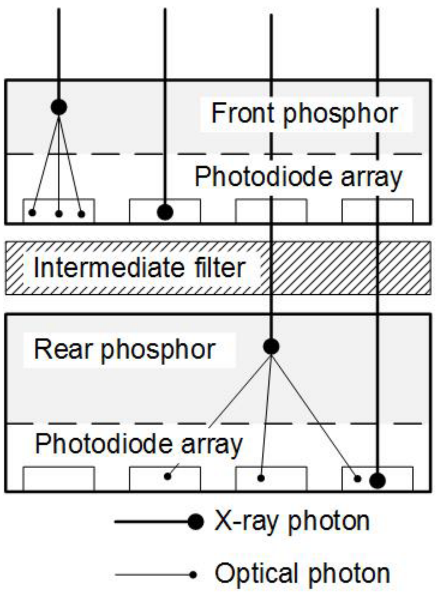
    decomposition of the measured data or images into contributions due to the two "basis materials"

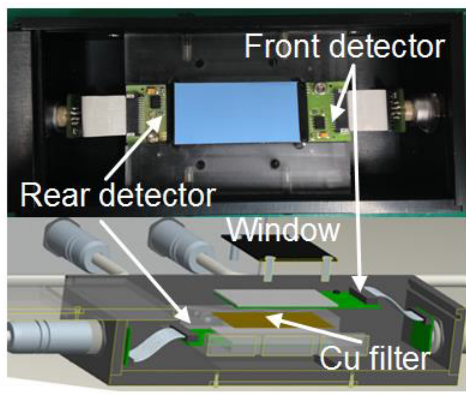


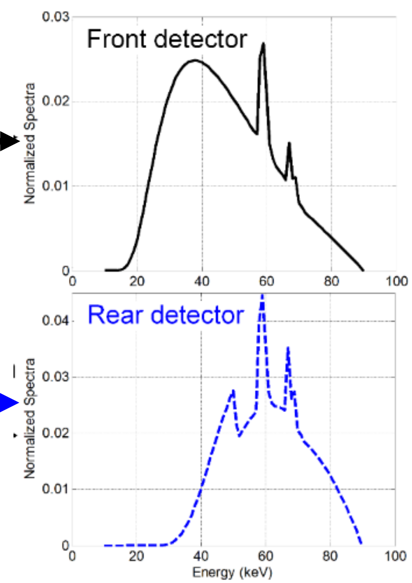
A. Altman, R. Carmi, Philips Healthcare

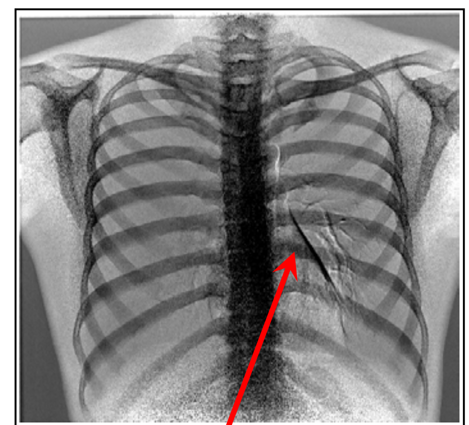
Single-shot dual-energy imaging

- Single-shot dual-energy (SE) imaging acquires two images with a single exposure
- With SE, motion artifacts due to heartbeat or patient motion can be avoided and irradiation dose can be reduced









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Pusan National University
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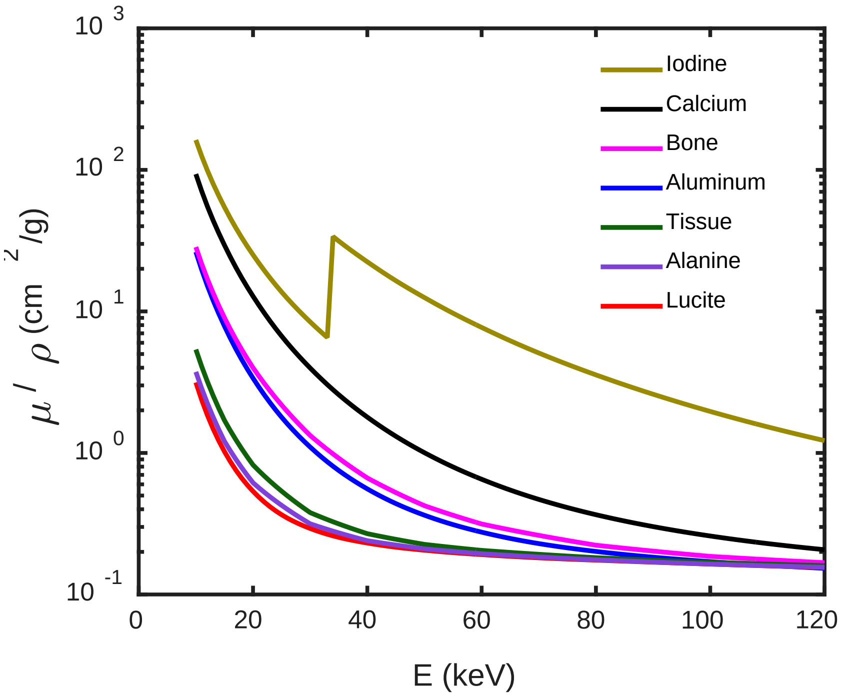
Attenuation coefficients

- The mass attenuation coefficients (MACs) of various materials have different values
- Particulary, materials constituting the human body and contrast agents have different MACs



Energy [keV]	Mass attenuation coefficient [cm^2/g]			
	Lucite	Tissue	Al	Bone
30	0.293	0.379	1.101	1.330
40	0.231	0.269	0.557	0.666
60	0.191	0.205	0.276	0.315
80	0.175	0.182	0.202	0.223
100	0.164	0.169	0.171	0.186
120	0.155	0.160	0.153	0.168

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Pusan National University
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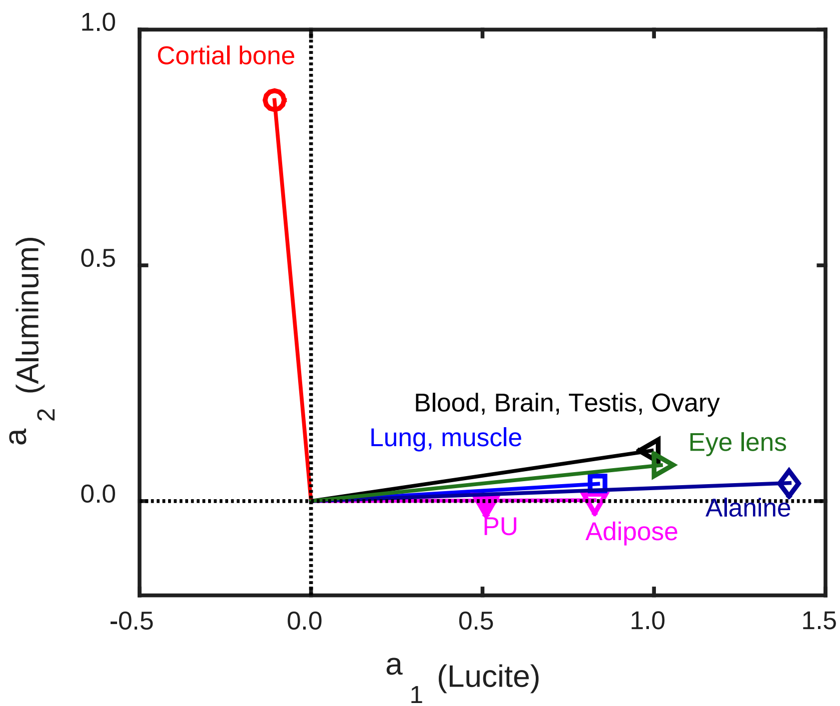
Basis function

- The MAC $\mu_\xi(E)$ of any arbitrary material ξ can be represented as a linear combination of two MAC $\mu(E)$ of basis materials
- Various materials can be coordinated using two basis materials



$$\frac{\mu_\xi(E)}{\rho_\xi} = a_1 \frac{\mu_1(E)}{\rho_1} + a_2 \frac{\mu_2(E)}{\rho_2}$$

$$\begin{bmatrix} \frac{\mu_\xi(E_L)}{\rho_\xi} \\ \frac{\mu_\xi(E_H)}{\rho_\xi} \end{bmatrix} = \begin{bmatrix} \frac{\mu_1(E_L)}{\rho_1} & \frac{\mu_2(E_L)}{\rho_2} \\ \frac{\mu_1(E_H)}{\rho_1} & \frac{\mu_2(E_H)}{\rho_2} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$\theta = \tan^{-1}\left(\frac{a_2}{a_1}\right)$$

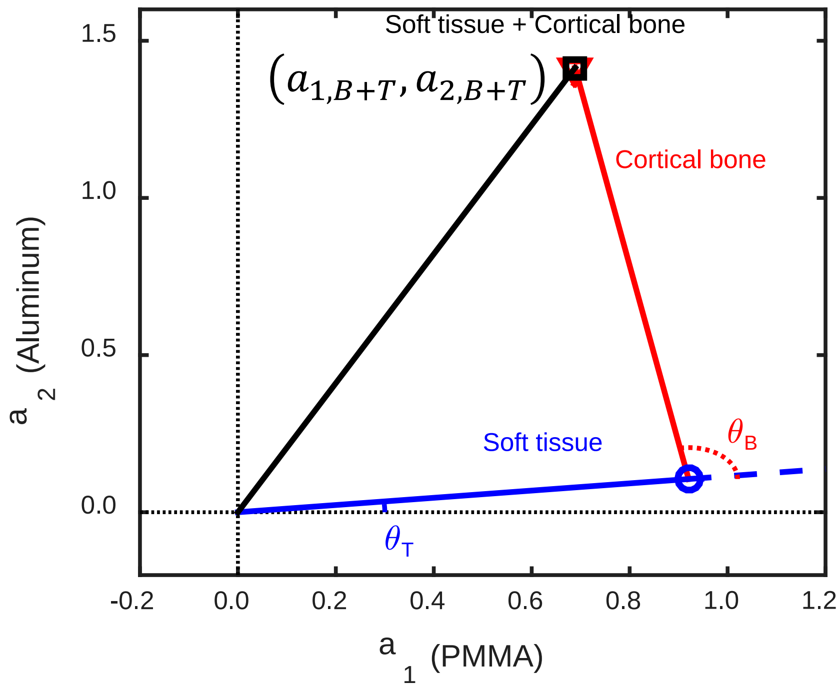
R. E. Alvarez and A. Macovski, *Phys. Med. Biol.* (1976)
L. A. Lehmann et al., *Med. Phys.* (1981)

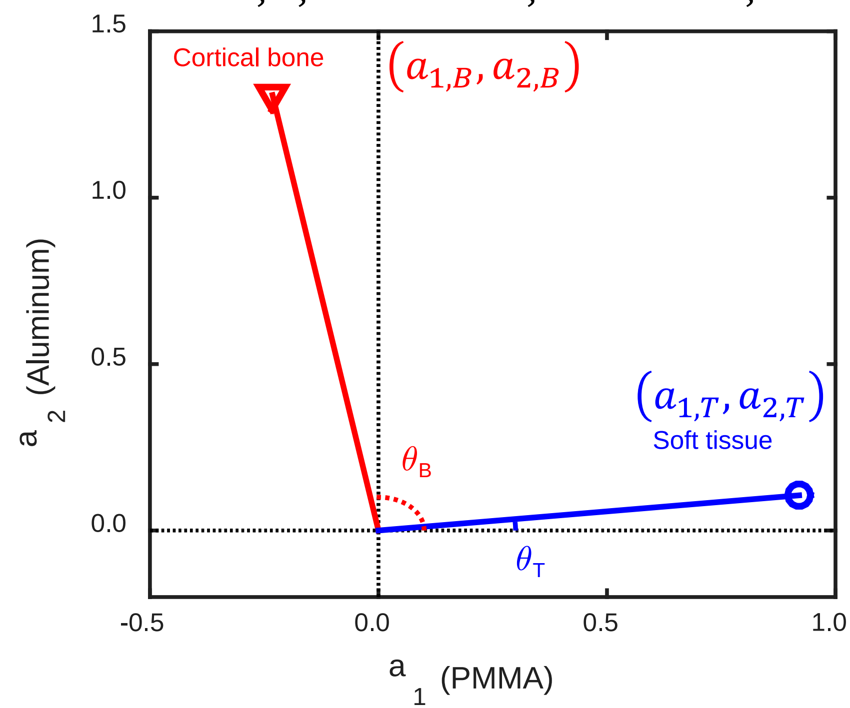
Radiation Imaging Laboratory,
Pusan National University
Dong Woon Kim {dongwoonkim@pusan.ac.kr}

Basis function

- The basis function vector in which the two materials are superimposed can be expressed by sum of the basis function vectors of each material
- The material decomposition is to identify the basis function vector describing each material

$$\mu_\xi t_\xi = A_1 \cos\theta_\xi + A_2 \sin\theta_\xi$$





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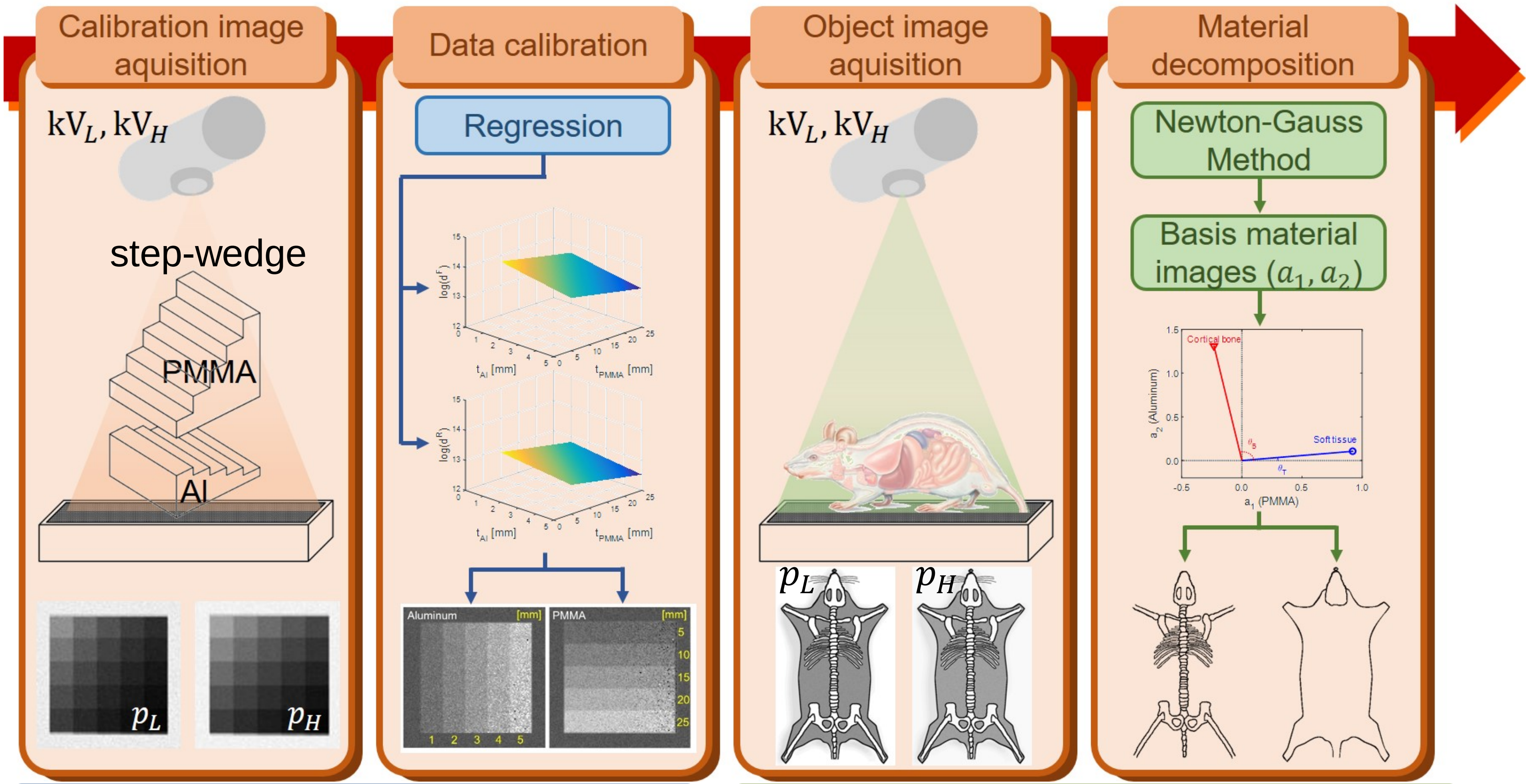
Basis material decomposition



$$p_i(A_1, A_2) = -ln \int \phi(E_i) e^{-A_1\mu_1(E_i) - A_2\mu_2(E_i)} dE$$

$$p_i(A_1, A_2) = b_{i1}A_1 + b_{i2}A_2 + b_{i3}A_1A_2 + b_{i4}A_1^2 + b_{i5}A_2^2$$

$$A_{j,n+1} = A_{j,n} - \left[p_L(A_{1,n}, A_{2,n}) \frac{\partial P_H}{\partial A_j} - p_H(A_{1,n}, A_{2,n}) \frac{\partial P_L}{\partial A_j} \right] / J$$

$$J = \frac{\partial P_L}{\partial A_1}\frac{\partial P_H}{\partial A_2} - \frac{\partial P_L}{\partial A_2}\frac{\partial P_H}{\partial A_1}$$

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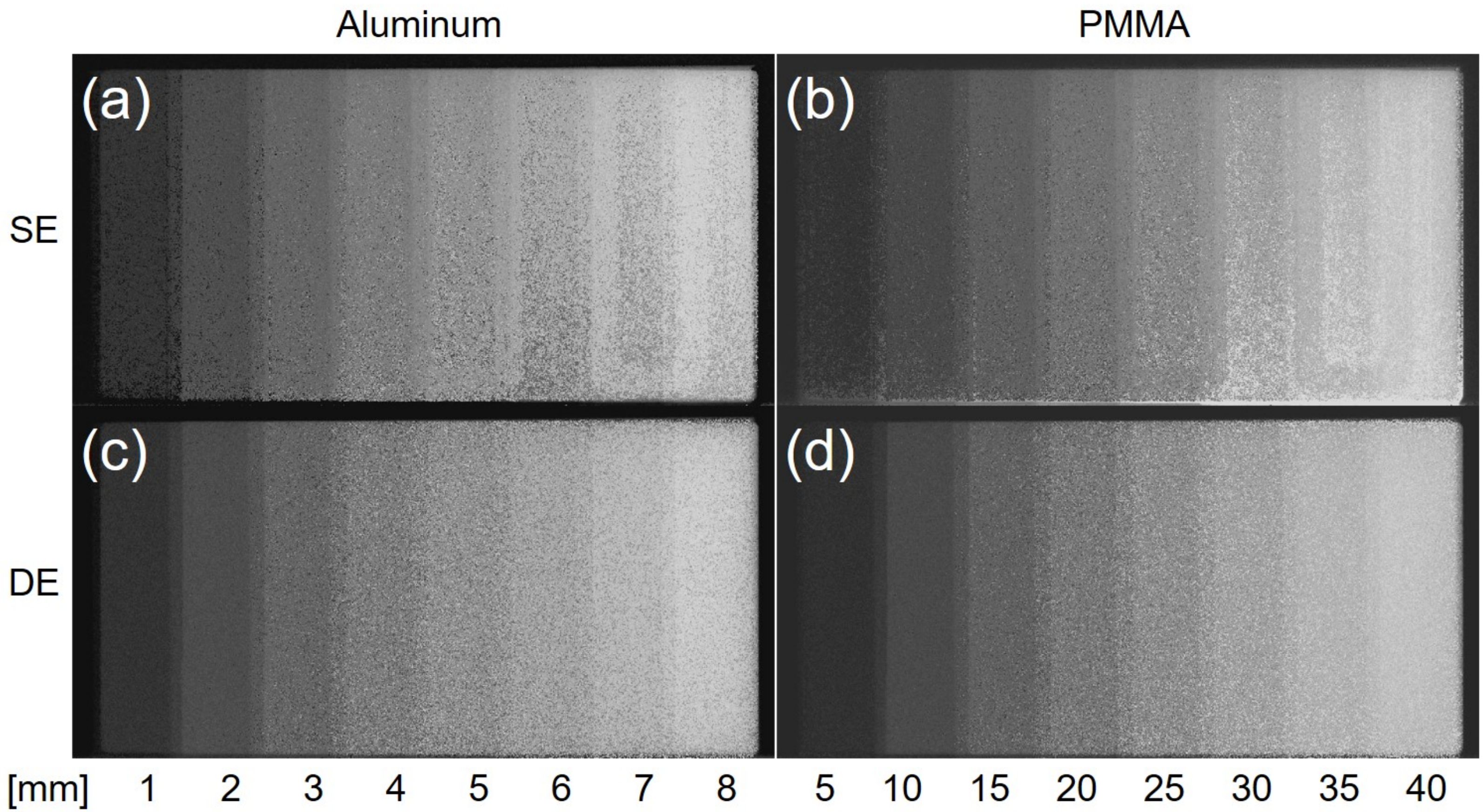
Results

- The thickness images of each material obtained using the regression analysis on the superimposed aluminum and PMMA phantom image



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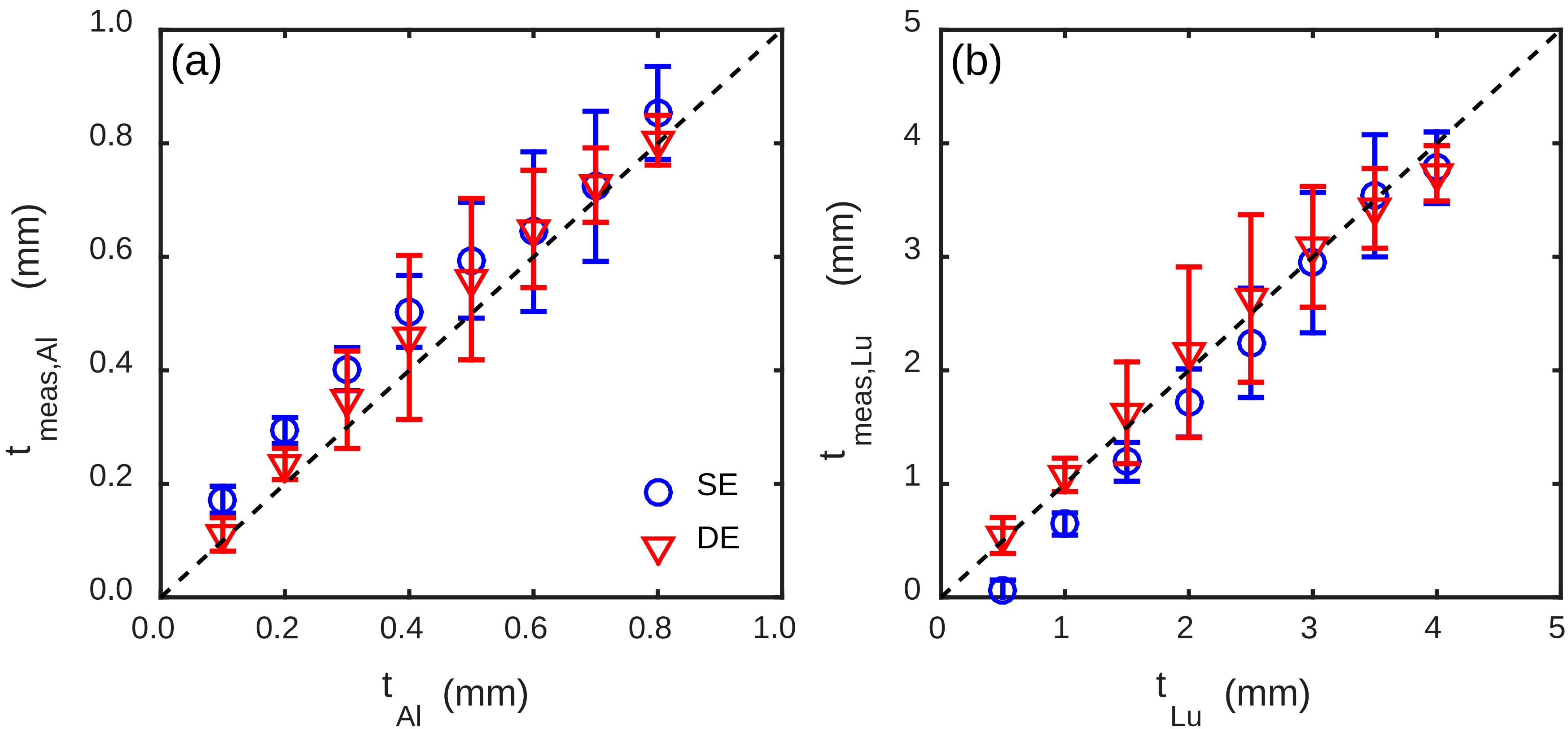
Dong Woon Kim {dongwoonkim@pusan.ac.kr}

Results

- Comparison of the measured Al / PMMA thicknesses and the phantom thicknesses
- The phantom thickness is reasonably estimated from the decomposed images. However, DE is better than SE



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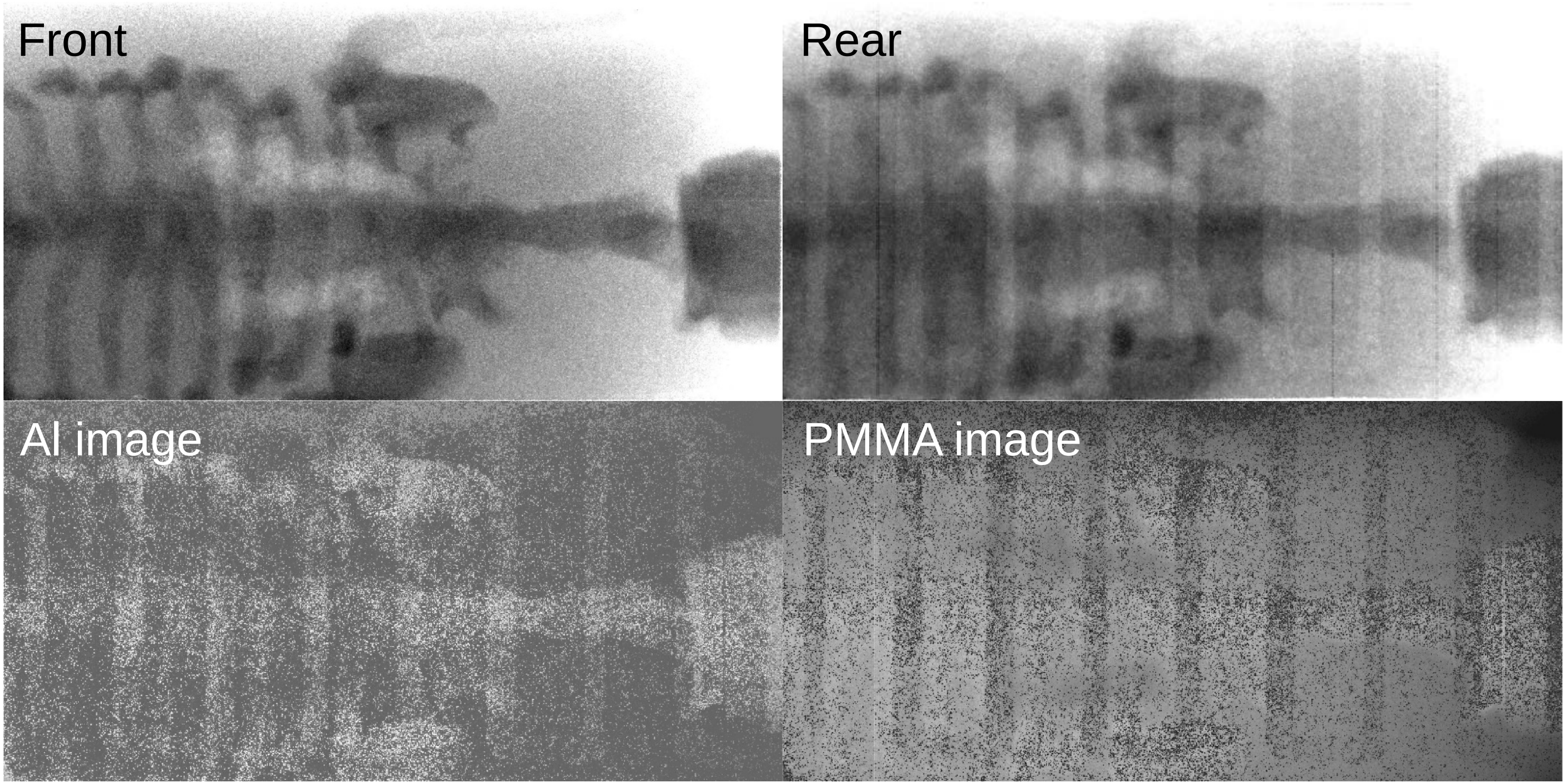
Results

- Basis material images obtained for the mouse phantom image using the sandwich detector



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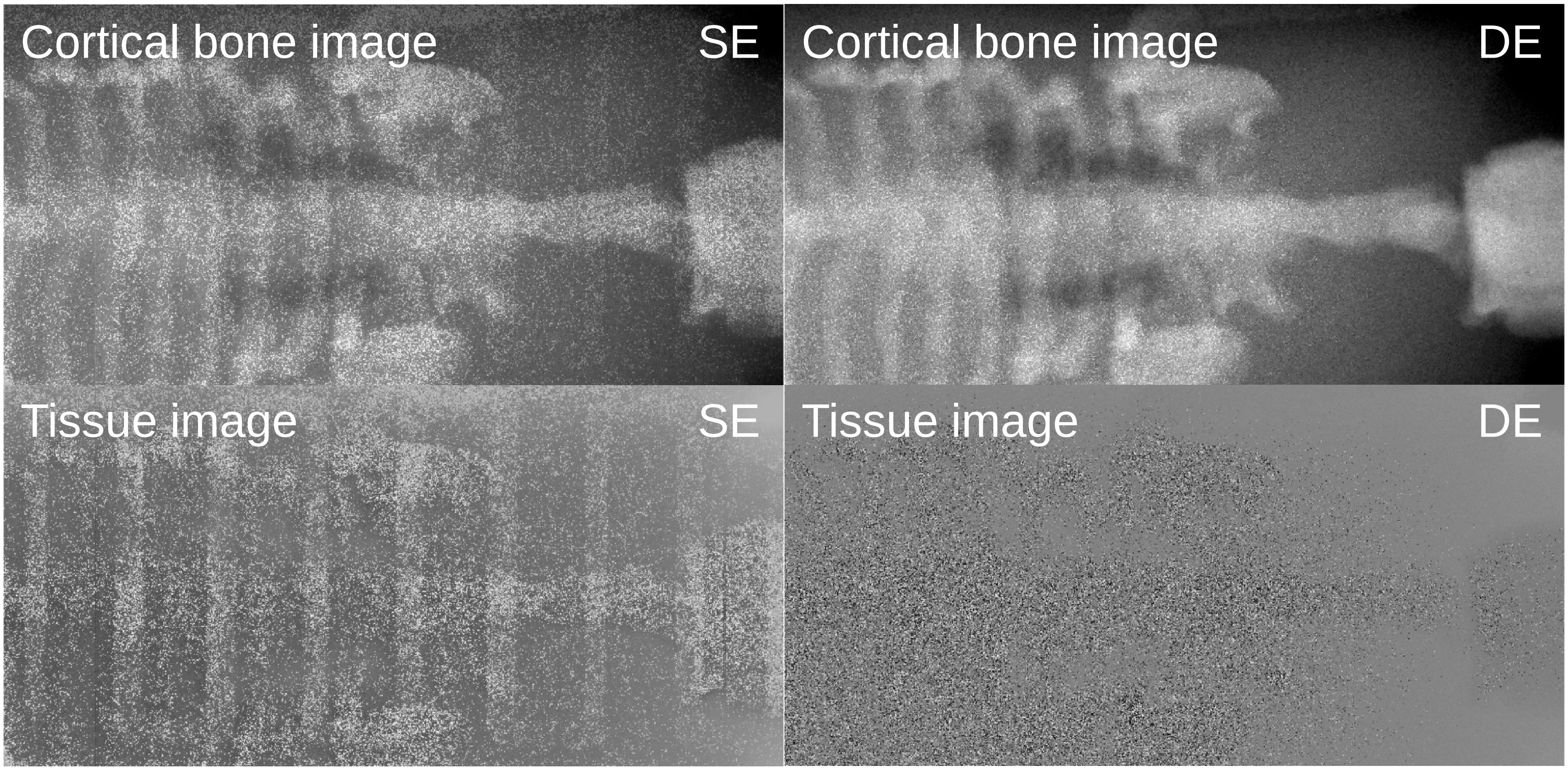
Results

- Cortical bone and tissue images using the basis function
- DE shows a better performance than SE, but SE is feasible for the material decomposition imaging



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Conclusion

- Basis material decomposition improves the conspicuity by removing the background clutters by vector operation using the basis function
- The projection signal of the wedge phantom can be described by the polynomials of two material thicknesses (from the calibration)
- Pixel signal of an arbitrary object can be expressed as the linear combination of two material thicknesses by solving the inverse of the polynomials
- We have validated the linearity of material-specific pixel signal using the wedge phantom
- We have verified the applicability of material decomposition radiography using the sandwich detector to bone and soft-tissue images of a mouse-mimetic phantom
- SE results show a sufficient feasibility

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