Synthesizing 100 kV and 120 kV CT images from dual-energy CT using a novel ray-by-ray effective energies

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Outline

- Background
- Purpose
- Methods
- Phantom studies
- Human subject studies
- Discussion and conclusion

Background: clinical motivation

- GE fast-kV switching-based dual-energy CT (DECT) acquires data at 80 kV, 140 kV and typically provides material basis images and virtual monoenergetic images (VME).
- Majority of the clinical contrast-enhanced chest and abdominal CTs are performed at 100 kV or 120 kV.
- Reference standards for the CT numbers of cystic renal masses, adrenal masses, liver fat fractions and other quantitative measurements are generally established based on 100 kV and 120 kV scans.

Purpose

- The purpose of this study is to leverage ray-specific effective energies extracted from DECT projection data along with material basis images to accurately synthesize 100 kV and 120 kV CT images desired by radiologists.

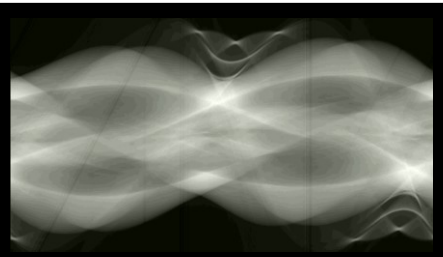
Effective energy

- Effective energy is a linearized representation of the ray-specific spectral information in the energy-integrating detector (EID).
- Instead of a joint function determined by entrance photon spectrum, attenuation by the image object and detector response function, a single value is extracted for each ray, satisfying the following equation:

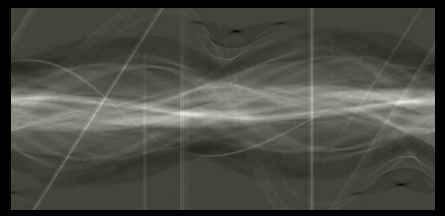
$$\log \frac{\overline{N_{0,i}}}{\overline{N_i}} = \bar{y}_i = p_{1,i}\, f_1(\xi_i) + p_{2,i} f_2(\xi_i)$$

where $\overline{N_{0,i}}$ and $\overline{N_i}$ denotes the average output counts of the EID at the *i*-th detector element for an air scan and an object scan, $\bar{y}_i$ is post-log projection datum, $p_{1,i}$ and $p_{2,i}$ are the line integrals of the spatial-dependent material concentrations, $f_1(\cdot)$ and $f_2(\cdot)$ are material-specific energy-dependent functions, ξ_i is extracted effective energy.

Methods: image synthesis workflow

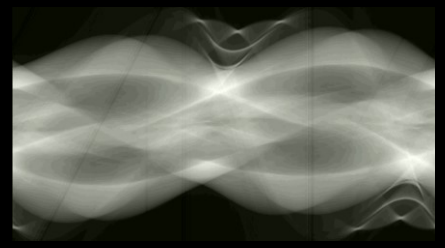


Line integrals of water basis image (p_1)

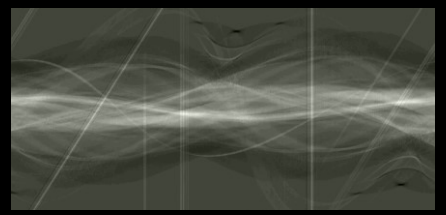


Line integrals of iodine basis image (p_2)

80 kV sinogram

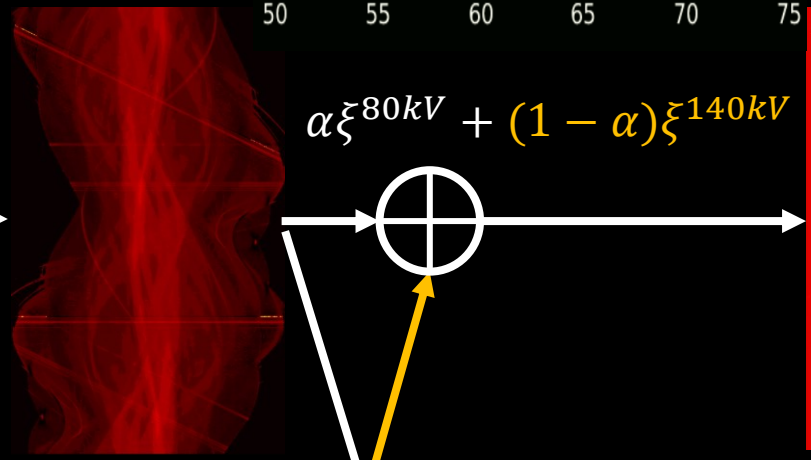


Line integrals of water basis image (p_1)



Line integrals of iodine basis image (p_2)

140 kV sinogram



Effective energy map at 80kV (ξ^{80kV})

$\alpha\xi^{80kV} + (1-\alpha)\xi^{140kV}$

Synthetic effective energy map at 100 kV

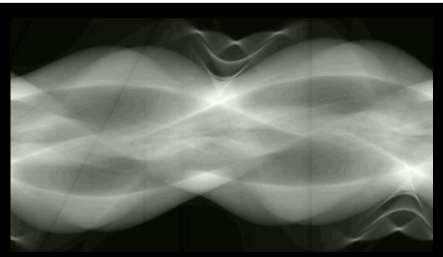
Effective energy map at 140 kV (ξ^{140kV})

$\beta\xi^{80kV} + (1-\beta)\xi^{140kV}$

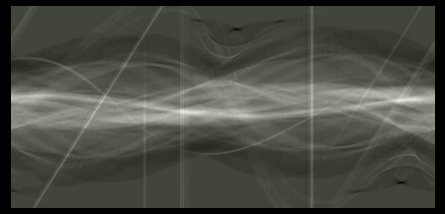
Synthetic effective energy map at 120 kV

Methods: image synthesis workflow

Synthetic effective energy map at 100 kV



Line integrals of water basis image (p_1)

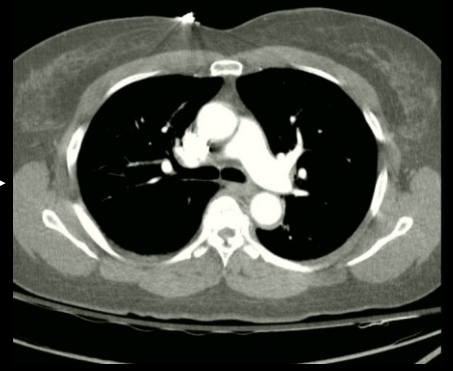


Line integrals of iodine basis image (p_2)

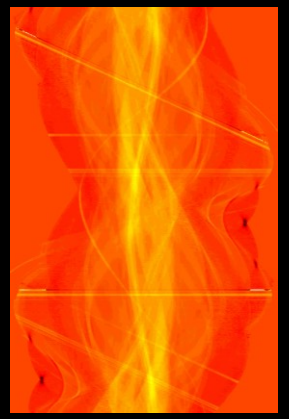
$$p_1 f_1\left(\xi^{100kV}\right) + p_2 f_2\left(\xi^{100kV}\right)$$

Synthetic sinogram at 100 kV

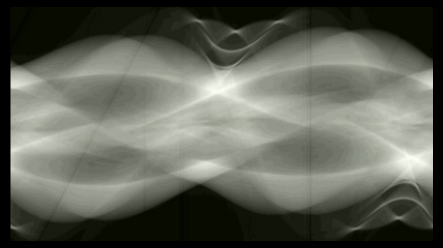
FBP



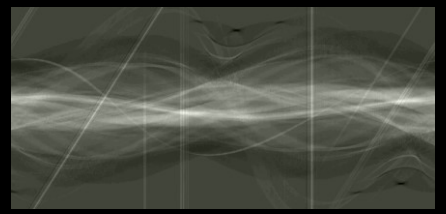
Synthetic image at 100 kV



Synthetic effective energy map at 120 kV



Line integrals of water basis image (p_1)

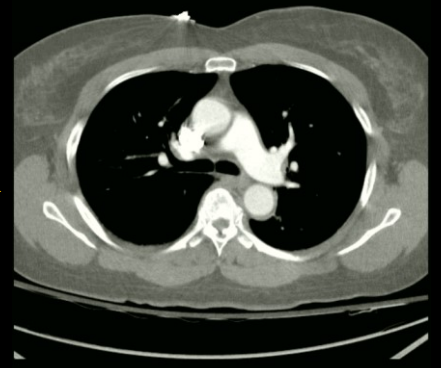


Line integrals of iodine basis image (p_2)

$$p_1 f_1\left(\xi^{120kV}\right) + p_2 f_2\left(\xi^{120kV}\right)$$

Synthetic sinogram at 120 kV

FBP

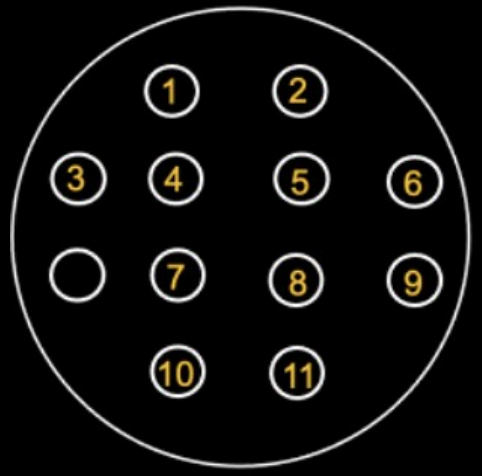


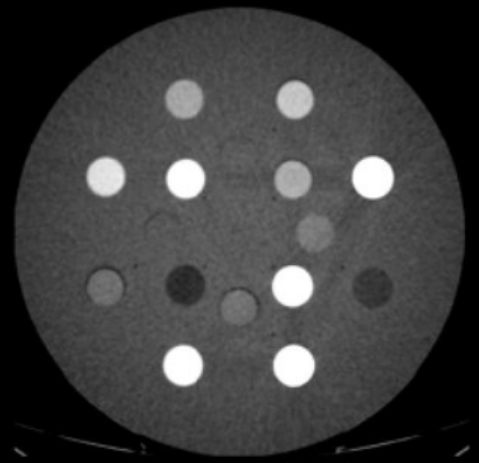
Synthetic image at 120 kV

Methods: implementation details

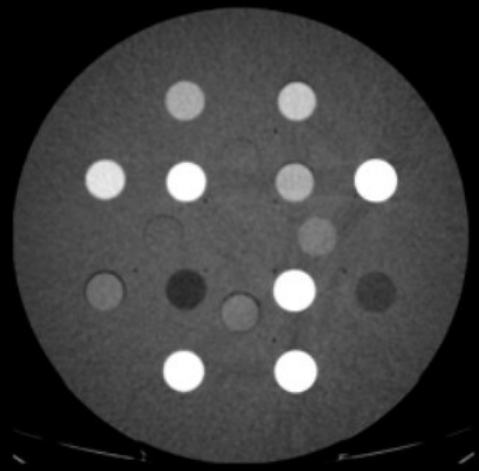
- System:
  - GE Discovery CT750 HD scanner
- Protocol:
  - Standard GSI scans
  - Standard 100 kV and 120 kV scans
- The weighting factors (i.e. α, β) were learned from CatPhan 600 with true 100 kV and 120 kV data. Once learned, the factors were directly applied to other physical phantoms and human subjects.
  - α is 0.56 for 100 kV and β is 0.25 for 120 kV
- Subjects:
  - Physical phantom (Gammex and Lungman)
  - Human subjects

Phantom studies: Gammex

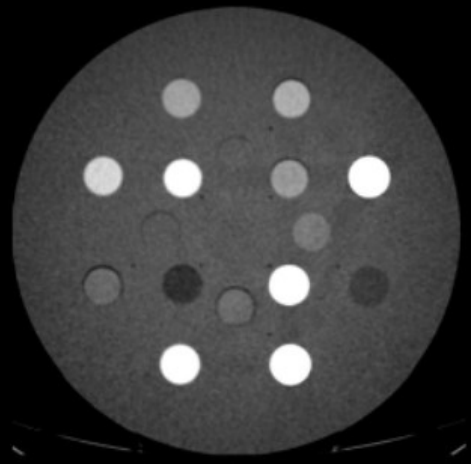




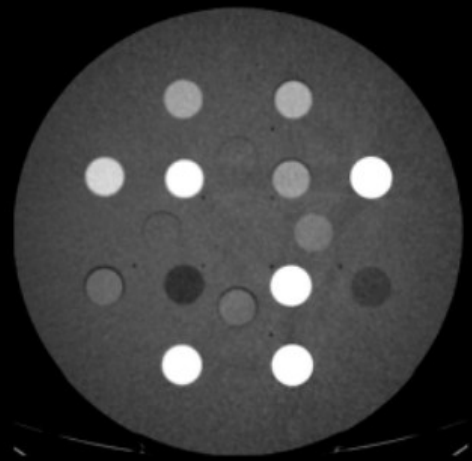
Synthetic 100 kV



True 100 kV



Synthetic 120 kV



True 120 kV

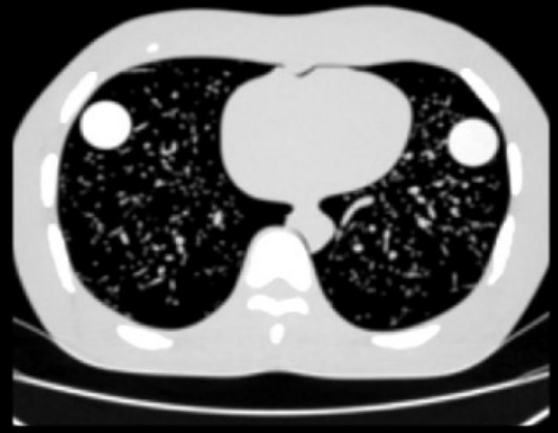
Phantom studies: Gammex

ROI #	Real 100 kV (HU)	Synthetic 100kV (HU)	Real – Synthetic at 100kV (HU)	Real 120kV (HU)	Synthetic 120kV (HU)	Real – Synthetic at 120kV (HU)
1	188 ± 13	190 ± 11	-2	176 ± 10	174 ± 11	2
2	261 ± 12	261 ± 12	0	201 ± 11	201 ±10	0
3	332 ± 11	333 ± 11	-1	296 ± 13	297 ± 9	-1
4	547 ± 11	540 ± 11	7	423 ± 11	421 ± 11	2
5	197 ± 12	197 ± 12	0	151 ± 12	152 ± 12	-1
6	1462 ±15	1460 ± 13	2	1271±14	1277 ± 11	-6
7	-96 ± 13	-93 ± 9	-3	-88 ± 11	-89 ± 9	1
8	918 ± 13	918 ± 12	0	803 ±14	806 ±11	-3
9	-68 ± 11	-64 ± 11	-4	-59 ± 12	-63 ± 10	4
10	618 ± 14	617 ± 13	1	550 ±12	546 ± 9	4
11	1172 ± 15	1174 ± 13	-2	1022 ± 13	1029 ± 12	-7

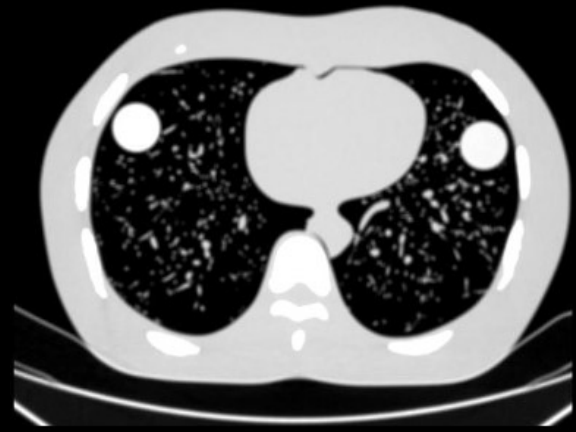
Phantom studies: Lungman

Synthetic 100 kV

True 100 kV



Synthetic 120 kV



True 120 kV

Phantom studies: Lungman

ROI #	Real 100 kV (HU)	Synthetic 100kV (HU)	Real – Synthetic at 100kV (HU)	Real 120kV (HU)	Synthetic 120kV (HU)	Real – Synthetic at 120kV (HU)
12	208 ± 6	210 ± 5	-2	193 ± 6	193 ± 5	0
13	156 ± 8	156 ± 9	0	122 ± 8	122 ± 7	0
14	446 ± 7	446 ± 5	0	406 ± 5	405 ± 5	1

Human Subject Studies

- CT triple-phase protocol with iodine contrast enhancement
  - Standard arterial phase (100 kV)
  - Late arterial phase (DECT)
  - 3 min Delayed phase (120 kV)
- Studied 5 human subjects
- Adipose tissues and bony structures were used to benchmark the accuracy of CT numbers in our proposed method

Human Subject Studies

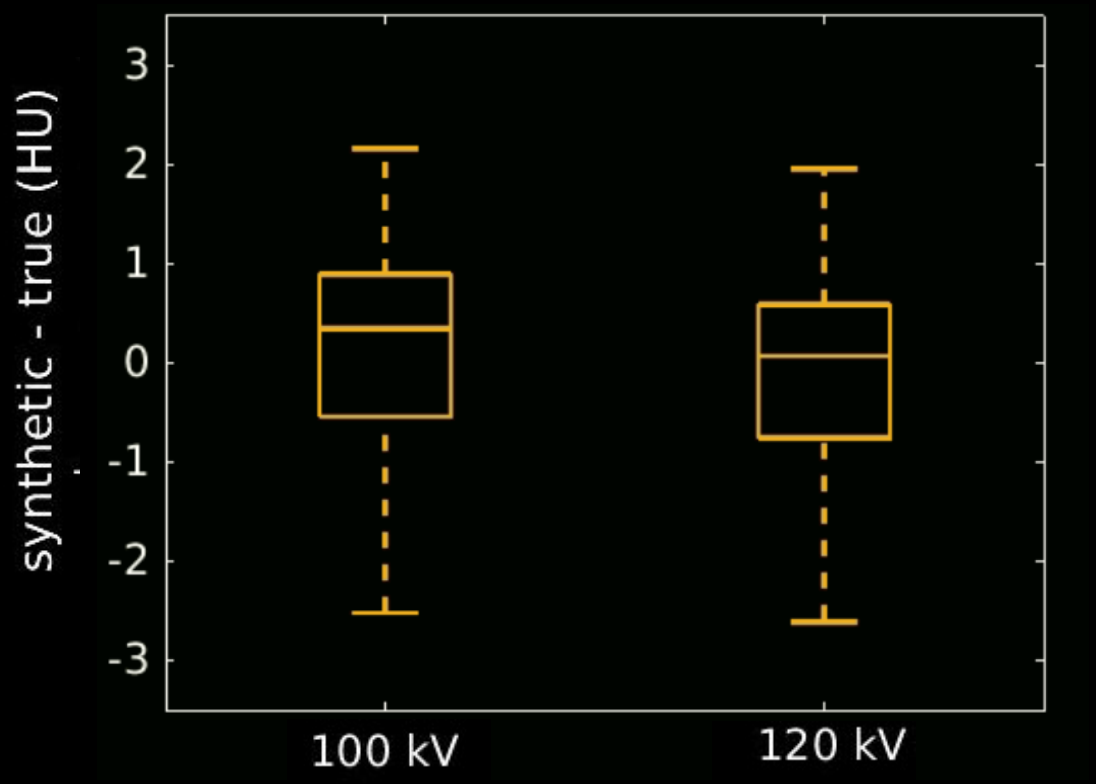
	True image	Synthesized image
100 kV		
120 kV		

W/L: 600/0

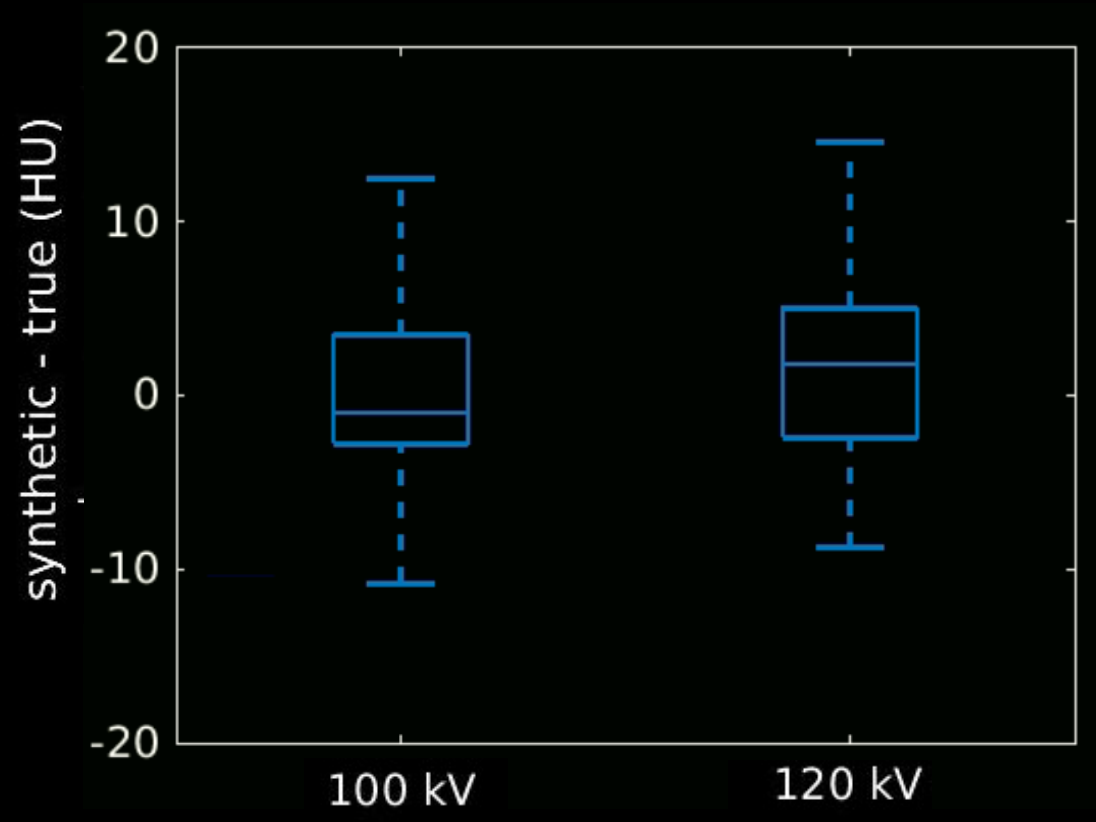
Human Subject Studies

- Box-whisker plot is used to analyze bias of adipose tissues, bony structures in human subjects.

43 ROIs measured in the adipose tissues



27 ROIs measured in the bones



Discussion and Conclusion

- For the Gammex and chest phantoms, CT numbers of all inserts were accurately depicted in the synthesized images with CT number errors less than 10 HU
- Box-whisker plot shows a near-zero bias at adipose tissues and bones of human subjects.
- Using ray-specific effective energies extracted from DECT data, virtual 100 kV and 120 kV CT images can be accurately synthesized without knowing the polychromatic spectra of each scanner.

Thank You

UW CT Research Group