Simulation and Removal of Metal Artifacts for Enhanced CT Imaging

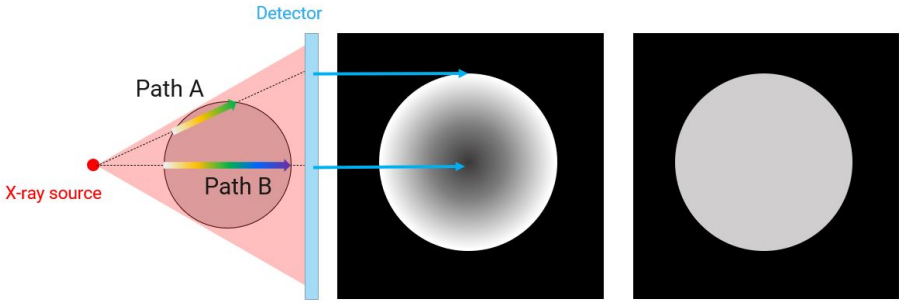
BENG 280A/ECE 207 Midterm Project

Benjia Zhang, Juo-Hsuan Chang, Iris Zaretzki

Outline

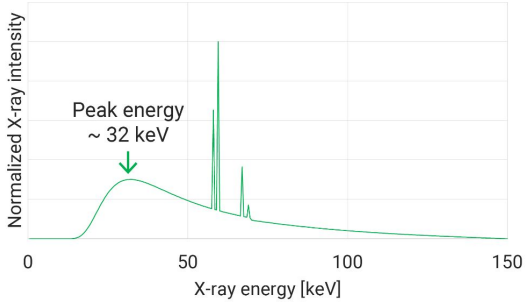
- Background Information
  - What causes metal artifacts?
- Simulation of Metal Artifacts
- Metal Artifact Removal

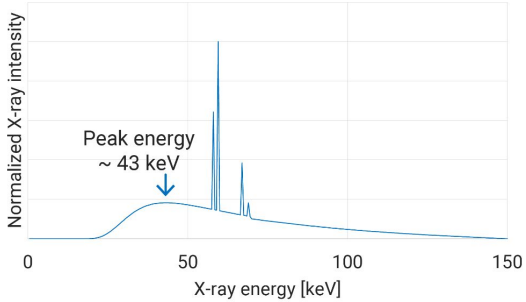
Beam Hardening



With beam hardening artifacts

Without beam hardening artifacts

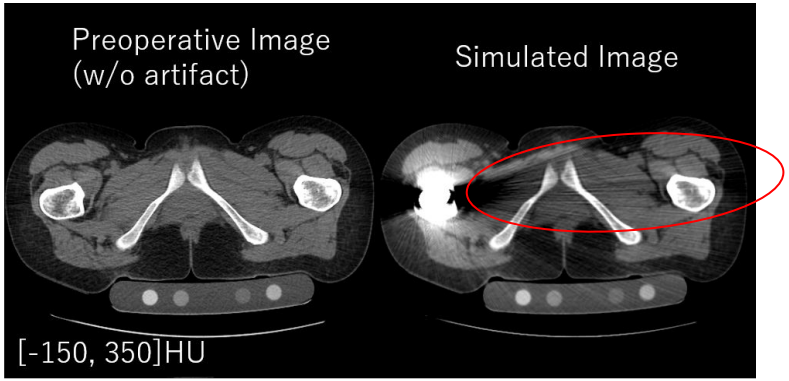


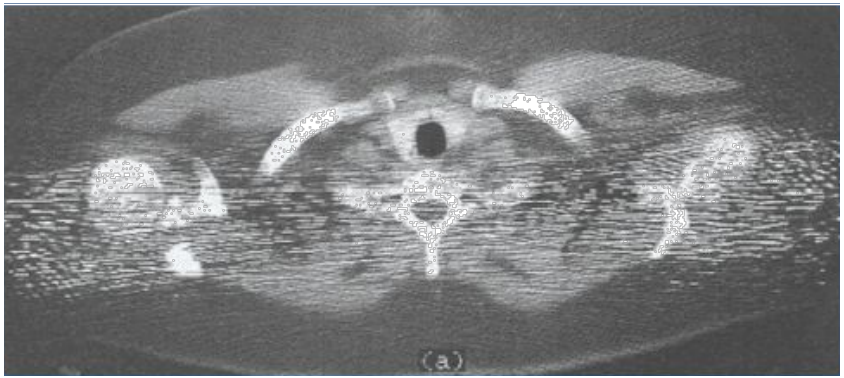


- Average x-ray energy increases when the beam goes through the body
- Darker center, brighter edges

Photon Starvation

- High density material absorb/scatter large amount of photons, resulting in a minimum amount hitting the detectors
- Streaks or speckled noise are created due to insufficient x-ray detection



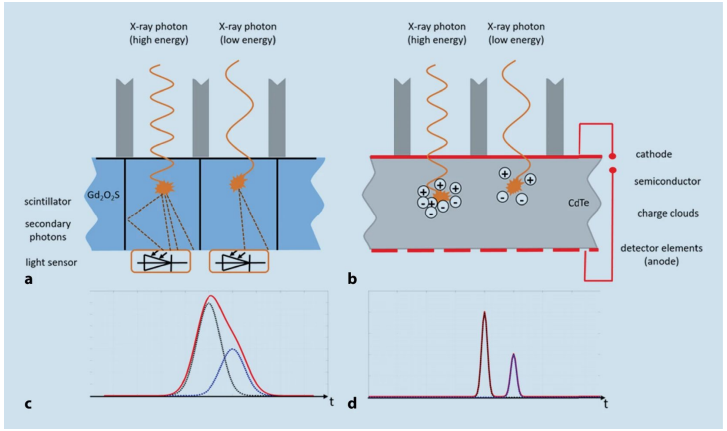


Methods

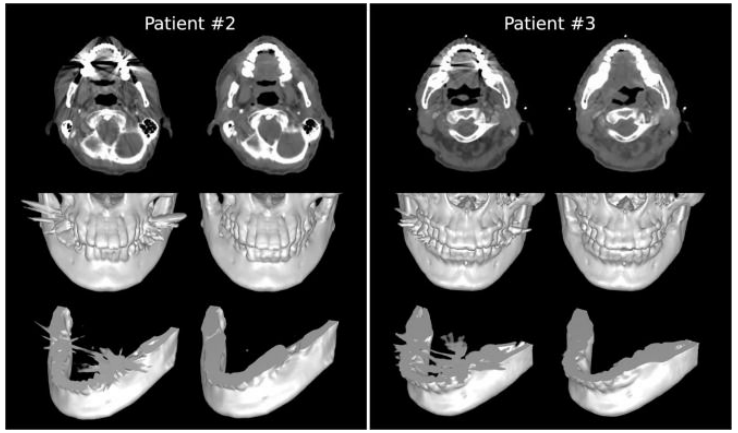
- Filtering, inpainting, and interpolation
- Projection-based Metal Artifact Reduction
- Analyzing and modifying the sinogram

Dual Energy

Photon Counting



Deep Learning



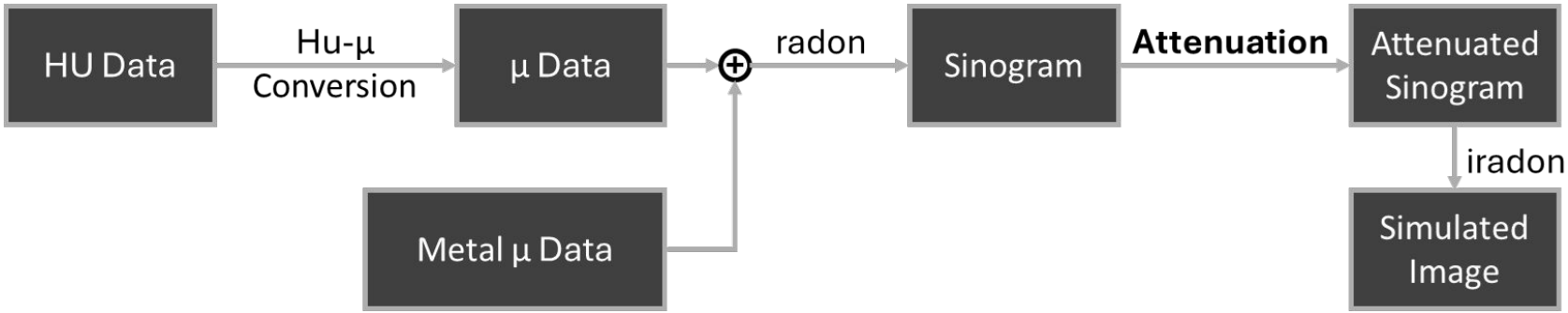
Simulation of Artifacts [1]

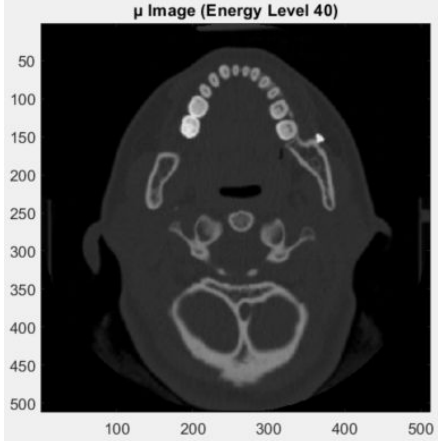
Photon Starvation

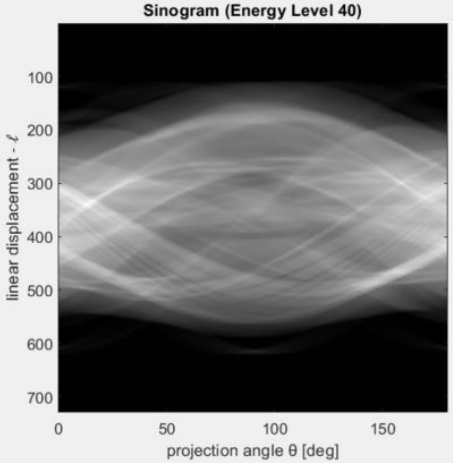
$$HU = 1000 \times \frac{\mu - \mu_{\text{water}}}{\mu_{\text{water}} - \mu_{\text{air}}}$$

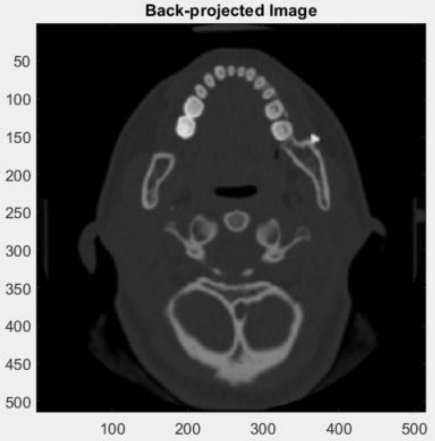
xray_characteristic_data.csv

	A	B	C	D	E	F
	xraycharacteristicdata					
	Energy	Water	Bone	Titanium	Iron	Intensity
	Number	Number	Number	Number	Number	Number
1	Energy	Water	Bone	Titanium	Iron	Intensity
2	1	4077	3781	5870	9085	0
3	2	617.3	586.9	986	1627	0
4	3	192.8	295.8	332	557.6	0
5	4	82.77	133.1	152	256.7	0
6	5	42.59	191.7	684	139.9	0
7	6	24.64	117.1	432	84.84	0
8	7	15.5	67.60988261	283	55.56	0
9	8	10.4	37.3	306	305.6	0
10	9	7.29	26.8	148	225.7	49.73536278
11	10	5.33	19.9	111	170.7	238.5495208
12	11	4.03	15.2	85	132.3	862.8132977
13	12	3.13	11.9	66.8	104.7	2196.270332
14	13	2.49	9.48	53.5	84.33	4420.964307
15	14	2.02	7.69	43.5	68.94	10421.40312




μ Image (Energy Level 40)
50
100
150
200
250
300
350
400
450
500
100
200
300
400
500


Sinogram (Energy Level 40)
linear displacement - ℓ
100
200
300
400
500
600
700
0
50
100
150
projection angle θ [deg]


Back-projected Image
50
100
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500
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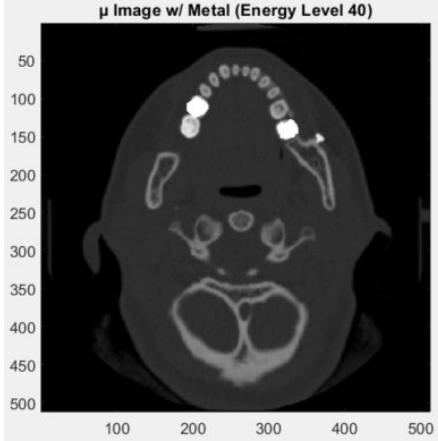
300
400
500


μ Image w/ Metal (Energy Level 40)
50
100
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300
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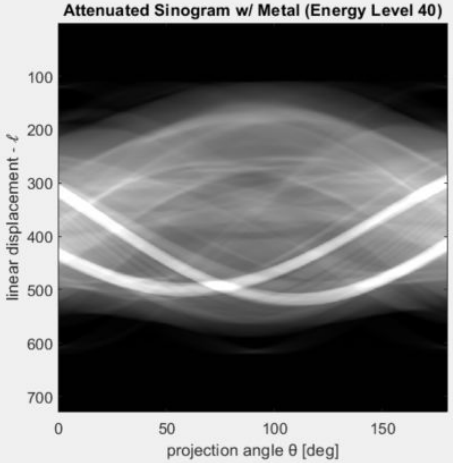
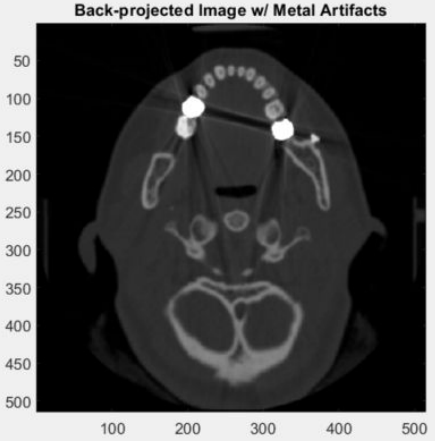
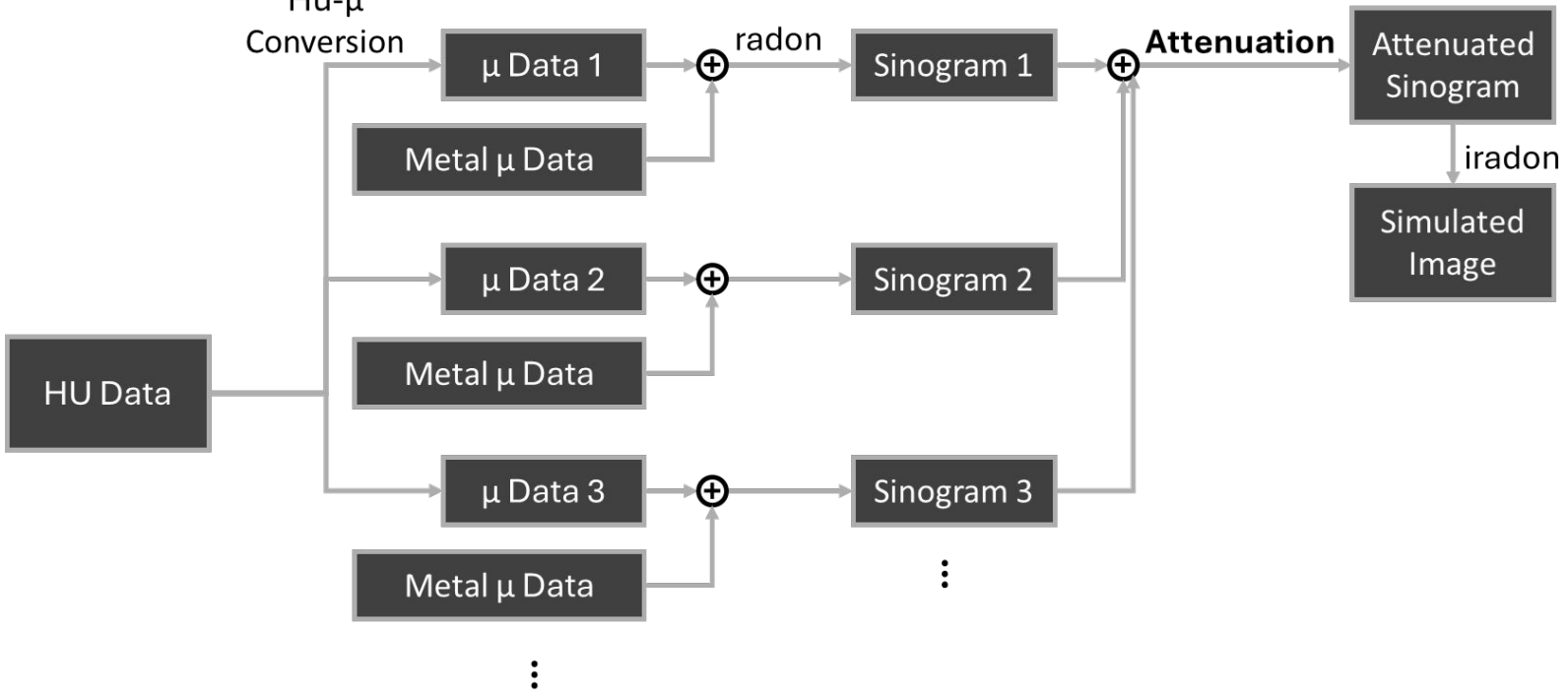
400
450
500
100
200
300
400
500

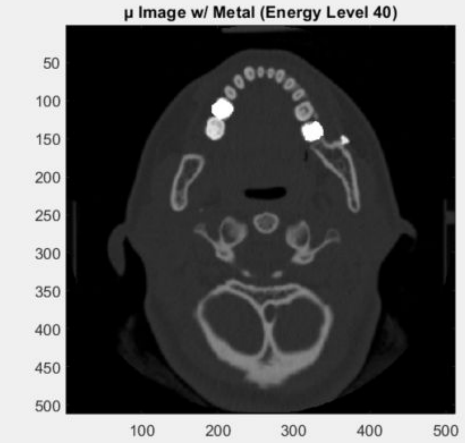

Attenuated Sinogram w/ Metal (Energy Level 40)
linear displacement - ℓ
100
200
300
400
500
600
700
0
50
100
150
projection angle θ [deg]

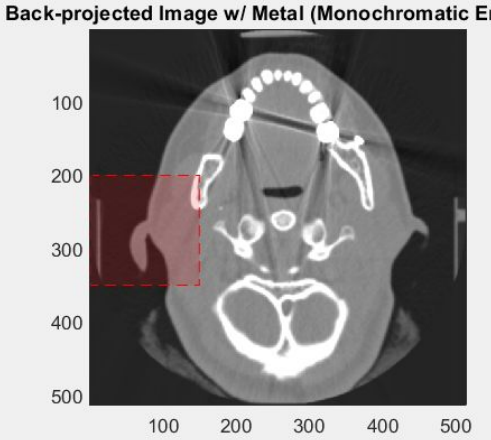

Back-projected Image w/ Metal Artifacts
50
100
150
200
250
300
350
400
450
500
100
200
300
400
500

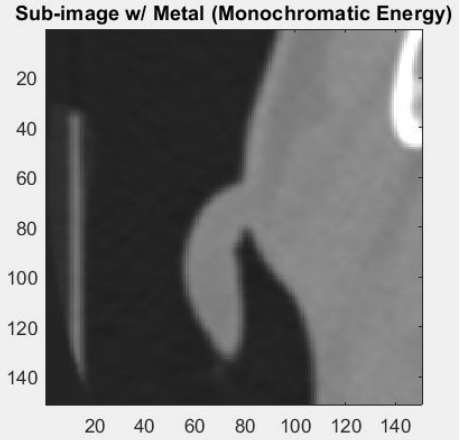
Simulation of Artifacts

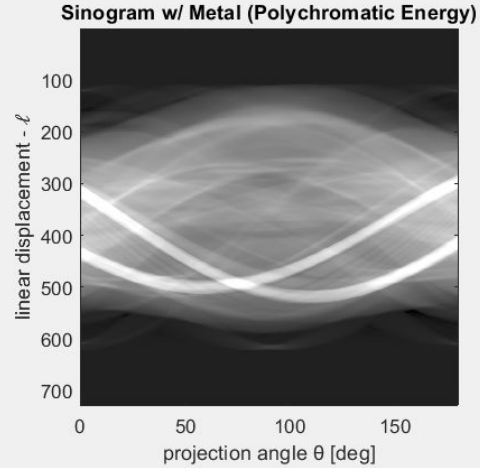
Beam Hardening [3]

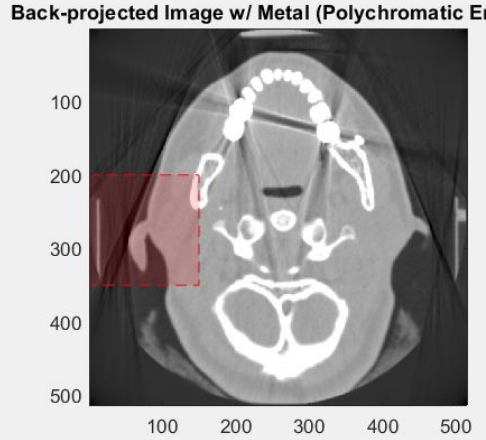


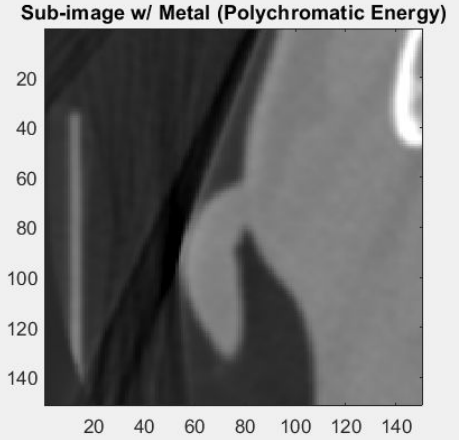

μ Image w/ Metal (Energy Level 40)
50
100
150
200
250
300
350
400
450
500
100
200
300
400
500


Back-projected Image w/ Metal (Monochromatic Energy)
100
200
300
400
500
100
200
300
400
500


Sub-image w/ Metal (Monochromatic Energy)
20
40
60
80
100
120
140
20
40
60
80
100
120
140


Sinogram w/ Metal (Polychromatic Energy)
linear displacement - ℓ
100
200
300
400
500
600
700
0
50
100
150
projection angle θ [deg]


Back-projected Image w/ Metal (Polychromatic Energy)
100
200
300
400
500
100
200
300
400
500


Sub-image w/ Metal (Polychromatic Energy)
20
40
60
80
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40
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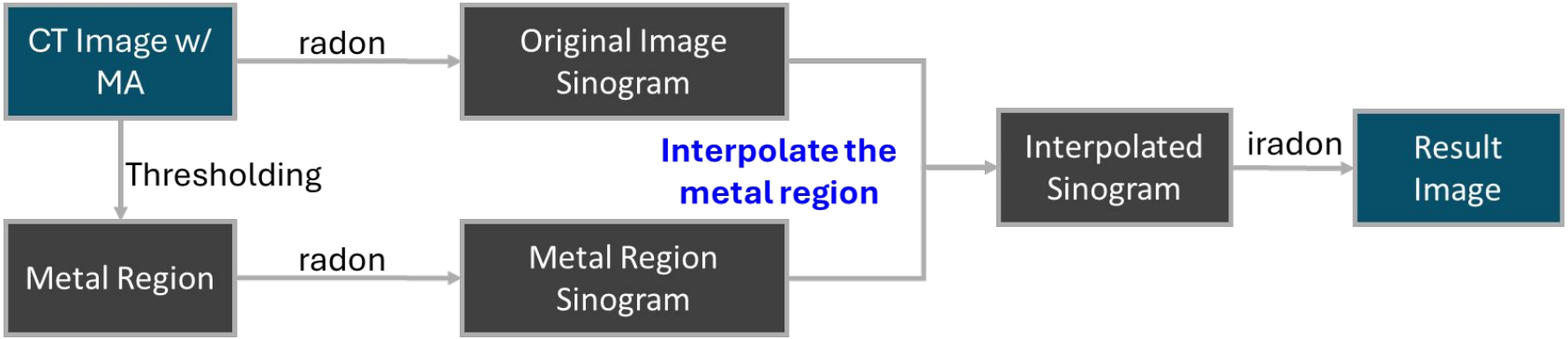
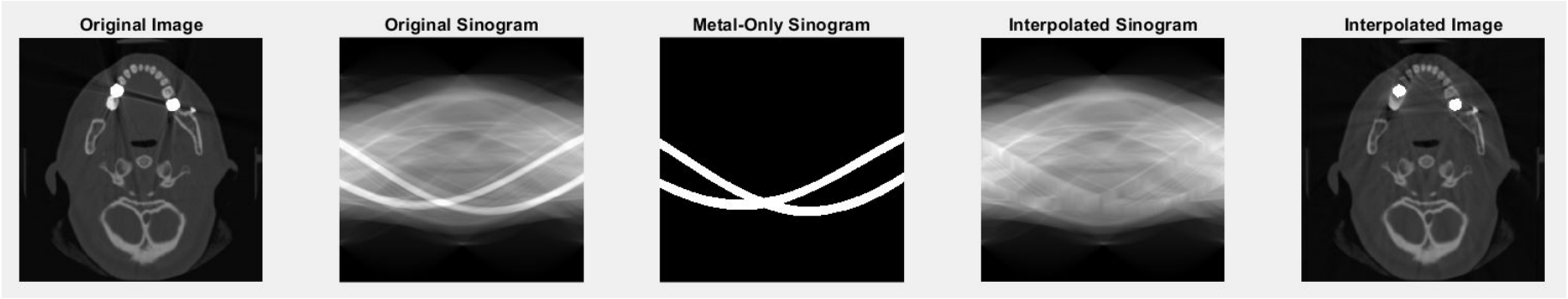
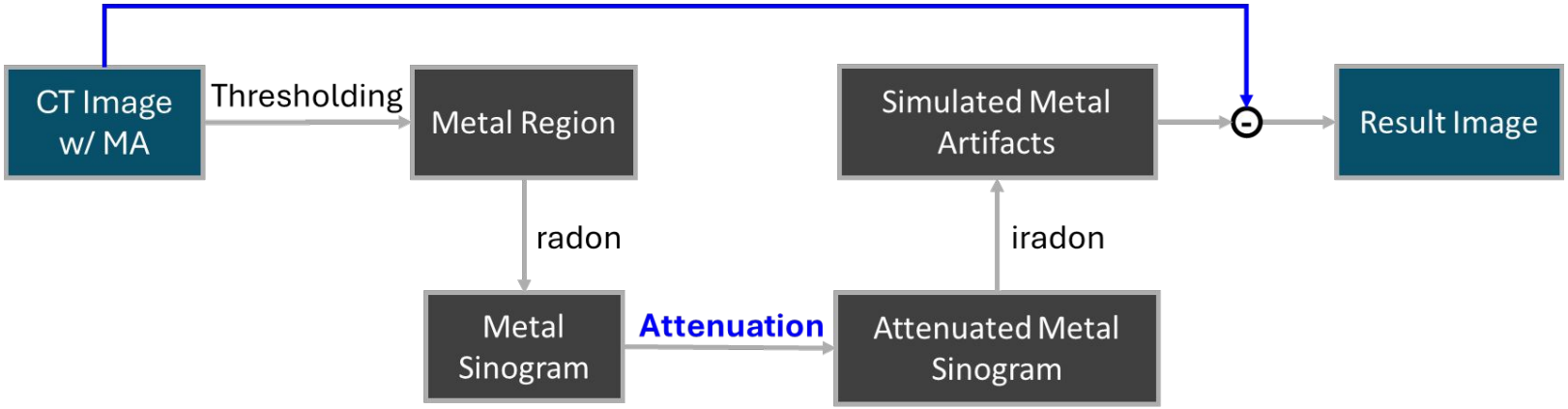
120
140

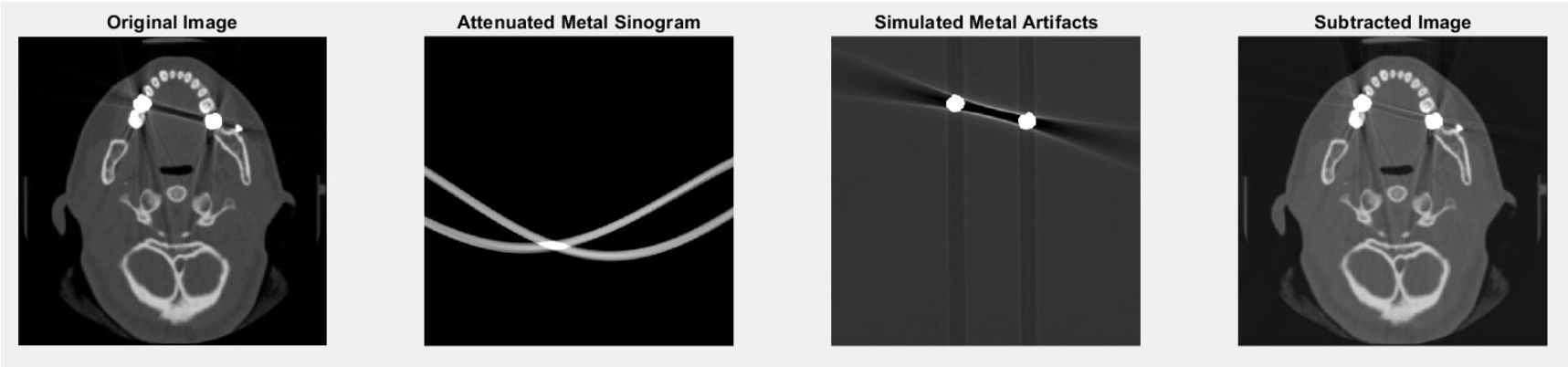
Sinogram Interpolation MAR



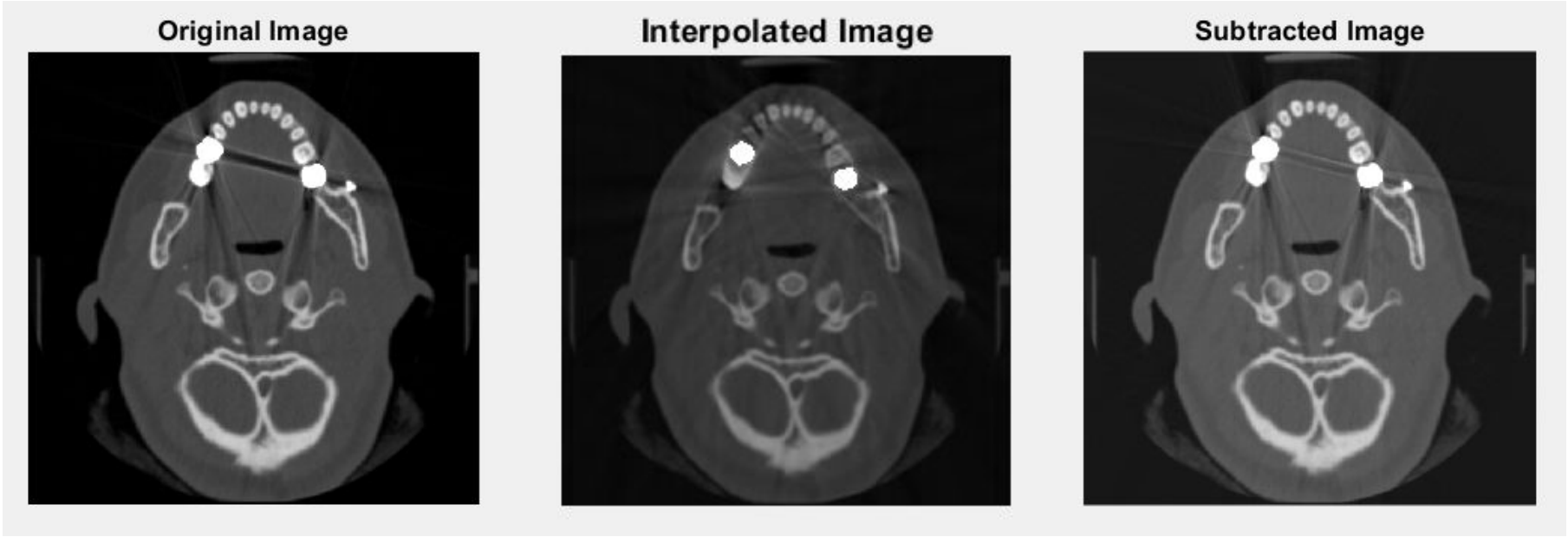


Simplified Iterative MAR Method





Results



Challenges & Future Work

- Challenges
  - Generalizing the algorithm to other images
  - Multiple iterations
- Future Work
  - Visualizing and comparing image quality
    - SD
    - CNR
    - Metal Artifact Noise
  - Exploring Deep-Learning/Inpainting Methods

Reference

[1] Sakamoto, Mitsuki & Hiasa, Yuta & Otake, Yoshito & Takao, Masaki & Suzuki, Yuki & Sugano, Nobuhiko & Sato, Yoshinobu. (2019). Automated Segmentation of Hip and Thigh Muscles in Metal Artifact-Contaminated CT using Convolutional Neural Network-Enhanced Normalized Metal Artifact Reduction.

[2] Mark Selles, Jochen A.C. van Osch, Mario Maas, Martijn F. Boomsma, Ruud H.H. Wellenberg, Advances in metal artifact reduction in CT images: A review of traditional and novel metal artifact reduction techniques, European Journal of Radiology, Volume 170, 2024, 111276, ISSN 0720-048X

[3] Herman G. T. (1979). Correction for beam hardening in computed tomography. *Physics in medicine and biology*, *24*(1), 81–106.

[4] Gutai, Andrea & Sekulić, Dunja & Spasojević, Ivana. (2022). Metal Artefact Reduction from CT Images Using Matlab. 10.1007/978-3-030-97947-8_17.

[5] Takasai, Aya. (2022). What is Beam Hardening in CT?

[6] “Metal Artifact Reduction for Orthopedic Implants (O-MAR).” Philips Healthcare, (2013).

[7] OpenAI. ChatGPT (November 6 version) [Large language model]. Responses to project title suggestions. Available at: https://chat.openai.com/. Accessed 2024.