Physics-Guided Deep Scatter Estimation by Weakly Supervision for Quantitative SPECT*

Hanvit Kim[1], Zongyu Li[2], Jiye Son[3], Jeffrey A Fessler[2], Yuni K Dewaraja[4], Se Young Chun**,[5]

[1]Electronics and Telecommunications Research Institute,
[2]Dept. Of EECS, University of Michigan,
[3]Interdiscip. prog. for Bioeng., Seoul National University
[4]Dept. Of Radiology, University of Michigan,
[5]Dept. Of ECE, INMC & IPAI, Seoul National University
**Corresponding Author

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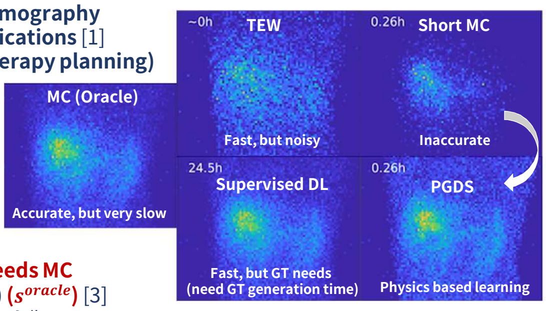
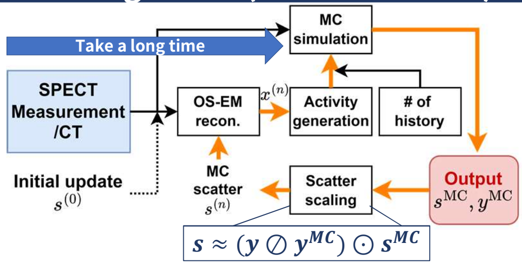
Motivation

- **Single photon emission computed tomography (SPECT) is important for clinical applications** [1] **(e.g., dosimetry guided treatment or therapy planning)**
- **Scattered photon in SPECT**
  - ➢ **Reduce the contrast**
  - ➢ **Introduce additional uncertainties**
- **The Monte-Carlo (MC) simulation showed accurate scatter estimation, but requires heavy computation** [2]
- **Supervised DL (deep learning) still needs MC simulation as Ground Truth (or label)** (s^{oracle}) [3]

$$L_{MSE}(h) = \|h(y^{oracle}; p) - s^{oracle}\|_2$$



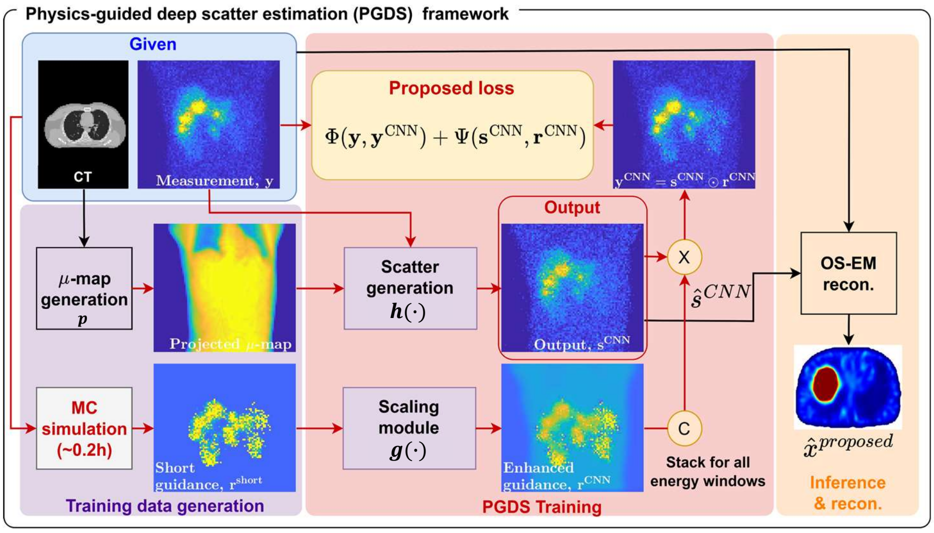
Background (MC simulation)



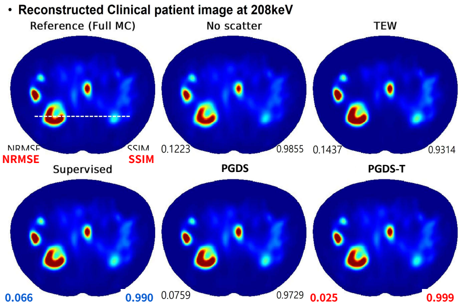
$$s \approx (y \oslash y^{MC}) \odot s^{MC} \quad (1)$$

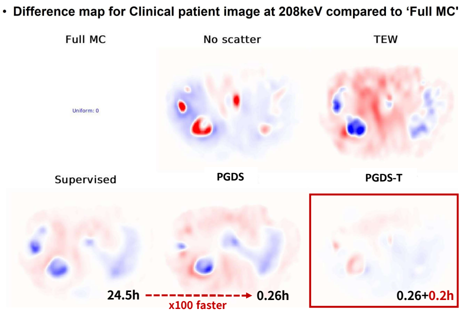
*The **ratio** of the unknown scatter component to the measured total projection **is proportional** to the ratio of those simulated by MC [4].*

Physics-Guided Deep Scatter (PGDS)



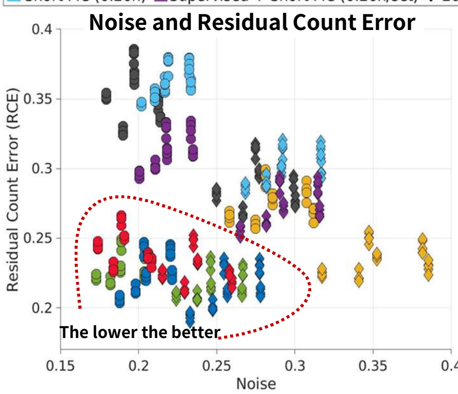
Results (Clinical data study)

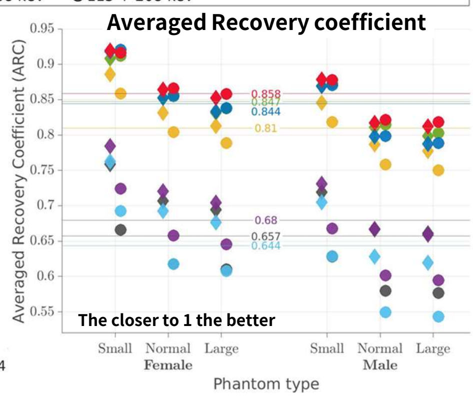




Quantitative evaluation

Oracle | No scatter (0h) | TEW (~0h) | Supervised (24.5h/set) | Proposed PGDS (0.26h/set) | Short MC (0.26h) | Supervised + Short MC (0.26h/set) | ◇ 208 keV | ○ 113 + 208 keV





Key points

① Physics-guidance (from short MC)

$$(y^{MC} \oslash s^{MC}) \odot \hat{s} \Rightarrow r^{MC} \odot \hat{s} \quad (2)$$

- r^{MC} denotes the proposed 'physics-guidance' ratio vector that can be **predicting the measurement (y) using the scatter estimates ($\hat{s}$)**.

$$r^{MC} \approx \hat{r}^{CNN} = g(r^{short}; p) \quad (3)$$

- We propose a weakly-supervised training for scaling module $g(\cdot)$ that enhance a 'short MC'.

② Physics-guided deep scatter estimation loss

$$y \approx \hat{y}^{CNN} \equiv \hat{r}^{CNN} \odot \hat{s}^{CNN} = g(r^{short}; p) \odot h(y; p) \quad (4)$$

- The scatter generation module $h(\cdot)$ and scaling module $g(\cdot)$ can predict the measurement
- The supervised loss ($L_{MSE}(h)$) can be replaced by jointly training for $h(\cdot)$ and $g(\cdot)$ with following **PGDS loss**

$$L_{PGDS}(g,h) = \Phi(y, \hat{y}^{CNN}) + \Psi(\hat{r}^{CNN}, \hat{s}^{CNN}) \quad (5)$$

- $\Phi(y, \hat{y}^{CNN})$ is Poisson negative log-likelihood and $\Psi(\cdot,\cdot) = c_1\|\hat{r}^{CNN} - r^{short}\|_1 + c_2\|\hat{s}^{CNN} - s^{short}\|_1$ is regularizer to avoid undesirable solution

③ Patient-specific fine-tuning (PGDS-T)

- Since our method requires short simulation as weak label, **PGDS-T enables the fine-tuning** of the trained networks to a given measurement and weak label via additional short MC simulation (0.2h is this study)

Summary

(Propose)	**Deep learning scatter estimation method for SPECT reconstruction**
(Purpose)	**Overcome the time-consuming step in supervised learning (label generation)**
(Method)	**Replacing SL (scatter compare) to weakly-SL (measurement compare)**
(How to)	**Using short MC for approx. ratio as physics-guidance & applying scatter scaling step**
(Result)	**Reduce label cost by a factor of 100 (24.5h/set to 0.26 h/set) with our PGDS**
(Achieve)	**Additional patient-specific fine-tuning (0.2h/set), yielded better reconstruction performance than SL (0.037 NRMSE)**

References and Acknowledgement

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