Beam-energy and depth-of-interaction estimation in MV imaging using a dual-ended readout

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INTRODUCTION

Conventional imaging devices have limitations that hamper their application in adaptive radiotherapy (ART). This work proposes a novel approach in x-ray imaging in radiation therapy. We demonstrate a proof-of-concept for the use of dual-ended detector designs to form images that inherently contain an assortment of beam-related information that are not readily available with conventional imaging designs.

AIM

The aim of this work is to demonstrate that a dual-ended x-ray imaging device can inherently recover x-ray-beam energy and depth-of-interaction information that cannot be recovered with conventional designs.

METHOD

Dual-ended x-ray imager concept:

- Two separate flat panel array detectors attached at the top and the bottom surface of an indirect converting material.
- Optical photons spread through the scintillator material to reach the top and bottom detector and generate signals in opposing pixels.
- Signal proportionality depends on x-ray interaction depth and beam energy.

Proof-of-concept design

- A pixelated bismuth germanate (BGO) scintillator with 3mm thickness and 0.5mm pixel pitch, was modelled in a Monte Carlo software.[1]
- Each pixel was optically isolated from neighboring pixels to minimize optical crosstalk.
- Two flat-panel detectors were used to detect the optical signal at the x-ray beam entrance (top) and one at the exit (bottom) of the scintillator.

Calibration

- Signal proportion and E_{avg}/D_{avg} relationship calibration using monoenergetic sources

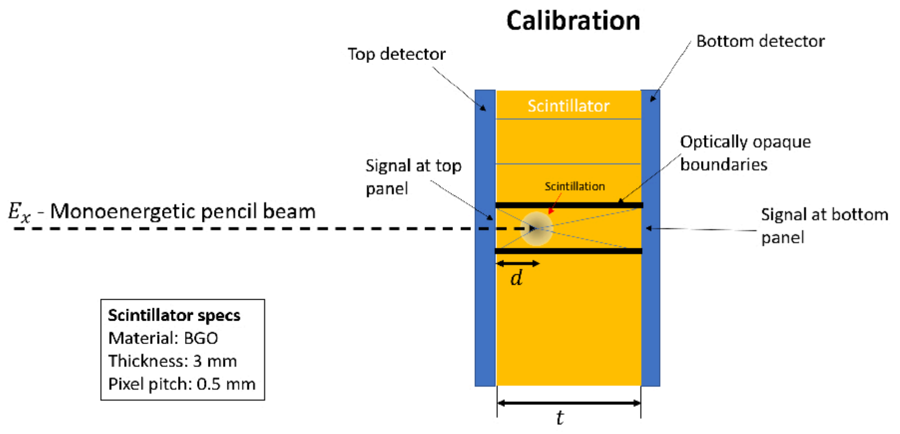
Images of beam-energy (E_{avg}) and depth-of-interaction (D_{avg})

- A phantom with three tissues (soft-tissue, bone and lung) was modeled.
- A 20x20 cm2 square field and a validated 2.5MV x-ray beam
- Top and bottom images were simulated. Images of D_{avg} and E_{avg} per pixel were generated using the signal proportion and the calibration curves
- E_{avg} and D_{avg} were calculated at specific regions-of-interest (ROIs) defined at each tissue

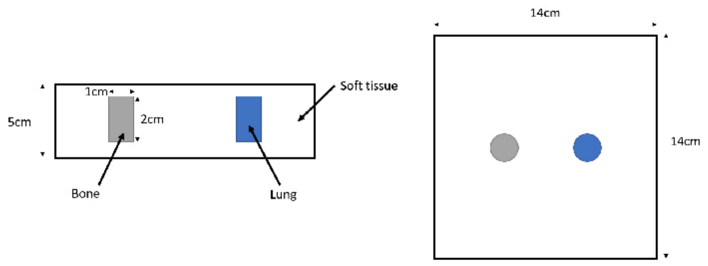
RESULTS

Dual-ended design and calibration

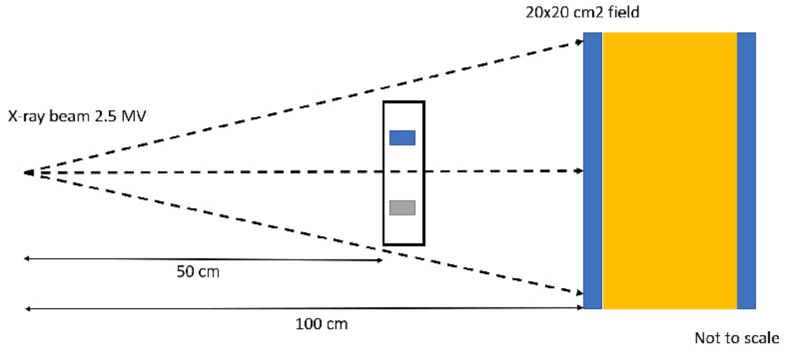
X-rays impinging in the top detector. Optical signal spread within pixel. Optical signal intensity depends on deposited energy. Opaque boundaries limit inter-pixel crosstalk.



Simple phantom with tissue-equivalent material

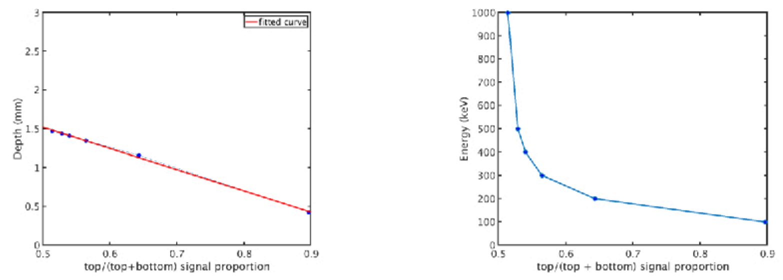


Phantom irradiation geometry



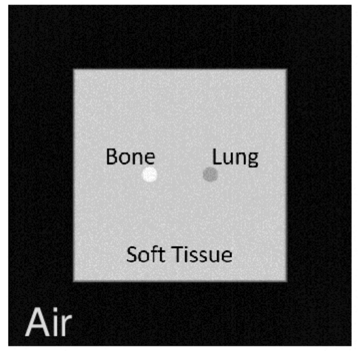
Calibration curves

Signal proportion calibrated with depth of interaction (left) and beam energy (right). A signal proportion of 0.5 indicates that top and bottom detector collect roughly the same signal. This is the case in higher energies (>200keV).



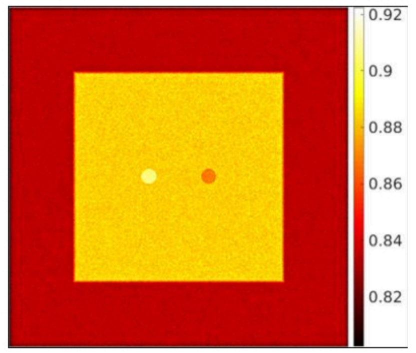
Images

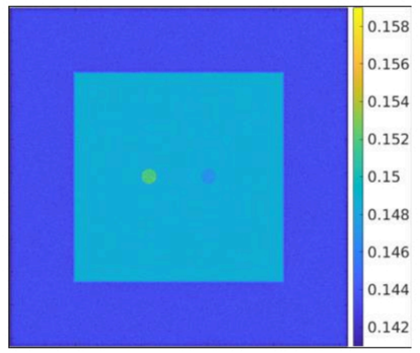
Intensity image generated on top detector (right)
Information contained in conventional images can also be obtained with the dual-ended design



E_{avg} (bottom right) and D_{avg} (bottom left) images were generated using the calibration curves.
Depth is shown in mm and energy in MeV.

In pixels corresponding to bone tissue the beam energy image shows higher energy, i.e. harder beam and longer interaction depth, i.e. more penetrating beam as expected. The reverse is true in lung tissue pixels.





D_{avg} and E_{avg} values in circular ROIs within the tissues of the phantom

	Air	Lung	Soft-tissue	Bone
D_{avg} (mm)	0.84 ($\pm 3.3 \times 10^{-3}$)	0.87 ($\pm 4.2 \times 10^{-3}$)	0.88 ($\pm 4.7 \times 10^{-3}$)	0.91 ($\pm 4.2 \times 10^{-3}$)
E_{avg} (MeV)	0.143 ($\pm 3.5 \times 10^{-4}$)	0.147 ($\pm 4.4 \times 10^{-4}$)	0.148 ($\pm 5.0 \times 10^{-4}$)	0.152 ($\pm 8.0 \times 10^{-4}$)

CONCLUSIONS

A proof-of-concept imager design with dual-ended detectors combined with pixelated scintillator demonstrated that x-ray beam energy and depth of interaction can be directly retrieved using signal proportions. Further work is required to optimize the design for improved energy separation and depth estimation in clinical conditions. The readout of average energy per pixel has potential utility in novel image reconstruction algorithms, in vivo dosimetry and adaptive radiotherapy, among other clinical applications.

- The proof of concept design is not specific to BGO. Any scintillation material that can be pixelated can be potentially used.
- Material selection and thickness will modify the quantum efficiency and affect the calibration curves, In this design energies higher than 200 keV cannot be adequately resolved.
- The x-ray beam spectrum affects the images. Higher content in low-energy x-rays (<150 keV) will likely improve recovery of D_{avg} and E_{avg}
- The dual-ended design can also be used with kV x-ray spectra similar to those used in radiological images with potential application in dual-energy imaging

ACKNOWLEDGEMENTS

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REFERENCES

1 **Sarrut D, Bardies M, Boussion N, et al.,** A review of the use and potential of the GATE Monte Carlo simulation code for radiation therapy and dosimetry applications, *Med Phys 2014; 41:064301*

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