Focused beam-stop array for megavoltage cone beam X-ray imaging

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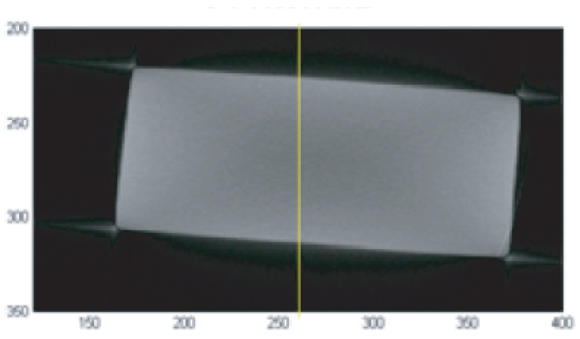
Objective

Scatter originating from the patient is a serious problem in cone beam imaging owing to the absence of detector collimation. We remove patient scatter from megavoltage X-ray cone beam projection images using a focused beam-stop array to **measure the scatter distribution**

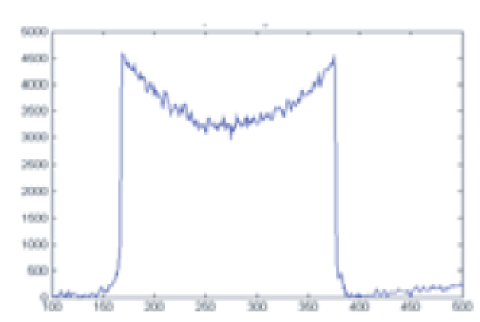
Megavoltage cone beam imaging is employed for for radiation treatment positioning guidance and absorbed dose reconstruction

Background

Patient scatter leads to cupping and streak artifacts in reconstructed tomographic images:

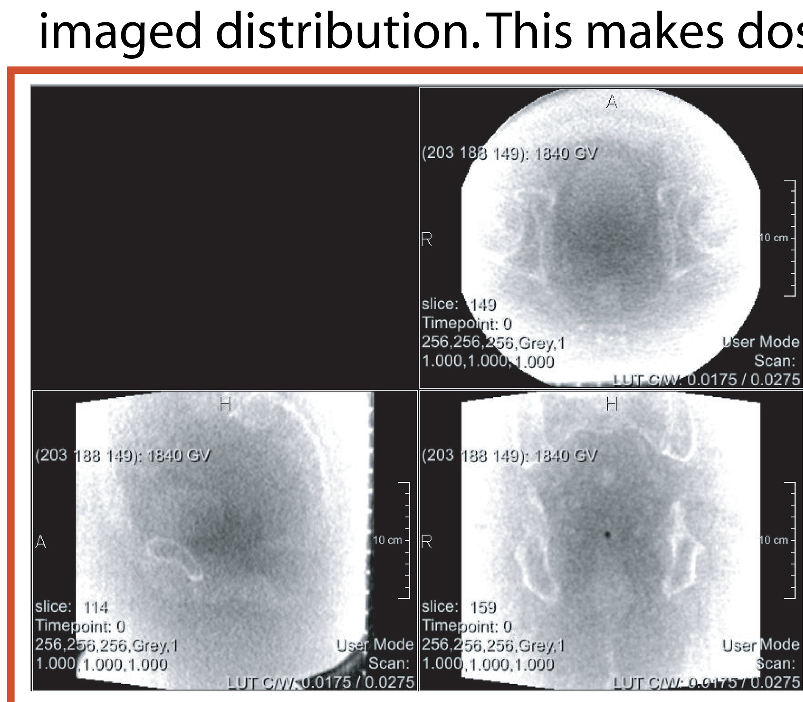


Example of cupping artifact due to scatter and beam hardening

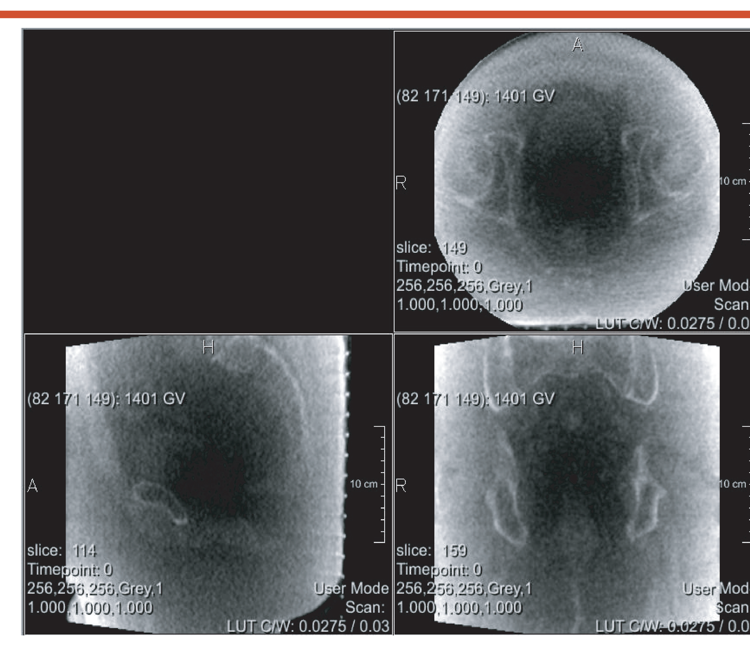


As a consequence:

1. Images are **difficult to view** using a single window and level setting.
2. The reconstructions do not accurately represent the electron density of the imaged distribution. This makes dose reconstruction difficult.



Adjusted for visualization of detail at image center



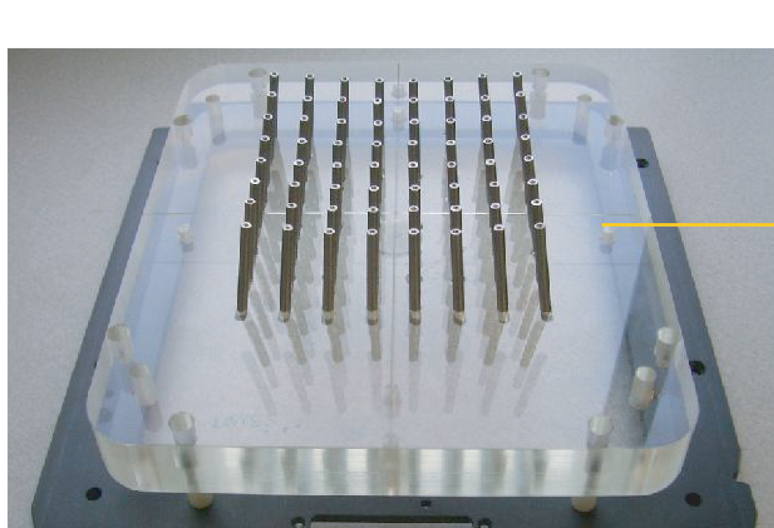
Adjusted for visualization of detail at image edges

Consider the reconstructed cone beam CT images of pelvic area shown above. The dark cupping artifact makes it difficult to use a single window and level setting to simultaneously obtain good viewing contrast at the center and edges of the image.

Many methods have been proposed for scatter reduction:

1. Antiscatter grids - not practical for highly penetrating MV photons.
2. Full Monte Carlo modeling - computational burden is prohibitive.
3. Convolution-superposition modeling with Monte Carlo scatter kernels - complicated implementation and may be inaccurate in some cases.
4. Heuristic methods based on approximate patient geometry - may be inaccurate
5. Measurement and subtraction of scatter.

We designed and implemented the first reported focused beam-stop array for the measurement of scatter in MV imaging

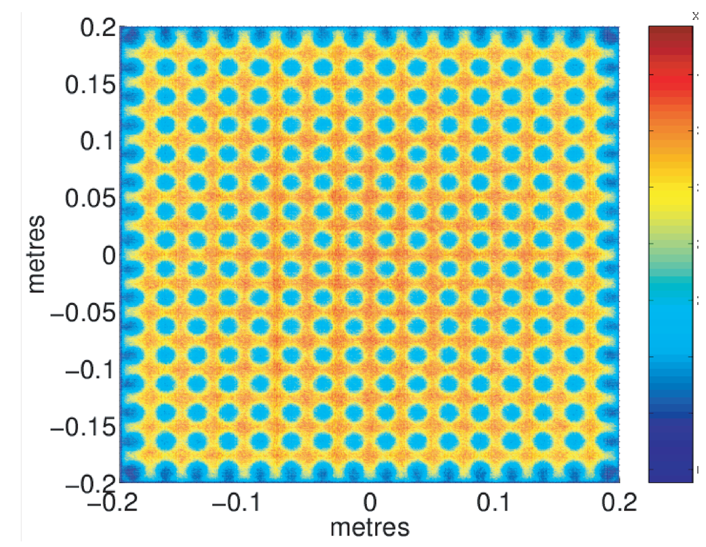


Beam-stop array with 64 tungsten doubly truncated cone elements of length 5cm and maximum radius 2.5mm

The beam-stop array is placed in accessory tray approximately 50cm from focal spot of linac. The linac is shown with flat panel extended and a pelvis phantom on the treatment table

Beam-stop array design

Owing to the highly penetrating nature of MV X-rays, long, highly-attenuating beam-stop elements are needed. The only practical implementation requires the use of doubly truncated cone elements that are **focused to the focal spot of the linac**. In the case of a spherically shaped detector, these cones case perfectly homogeneous shadows. Owing to the large source-to-detector distance (1.4m), the flat panel imager approximates the ideal spherical detector very well.



Performance of 256 element array simulated at 1MeV using the DOSXYZnrc user code of the EGSnrc Monte Carlo package. Detector dose at the flat panel imager is shown in arbitrary units.

Per-projection scatter measurement and removal procedure

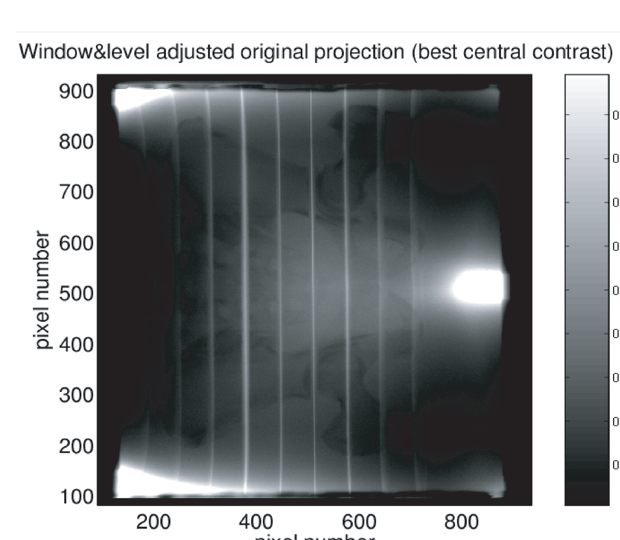
1. An image f_0 is taken **without the BSA or object to be imaged** in place.
2. An image f_1 is taken **with only the BSA and no object** in place.
3. An image f_2 is taken with **both the BSA and the imaged object** present.
4. An image f_3 is taken with the **BSA removed and the imaged object present.**
5. f_1 is processed to extract the values of this image in the regions **shadowed by the beam-stop elements.** The darkest 25% of pixels within each shadow are averaged to yield μ_1, a N^2-vector of means, where N is the number of beam-stop elements per row.
6. The corresponding means of these sets of pixels in the other 3 images, μ_0, μ_2 and μ_3.
7. The $N \times N$ coarse scatter measurement image is given by:

$$f_{sc} = (f_0 f_2 - f_1 f_3) / (f_0 - f_1)$$

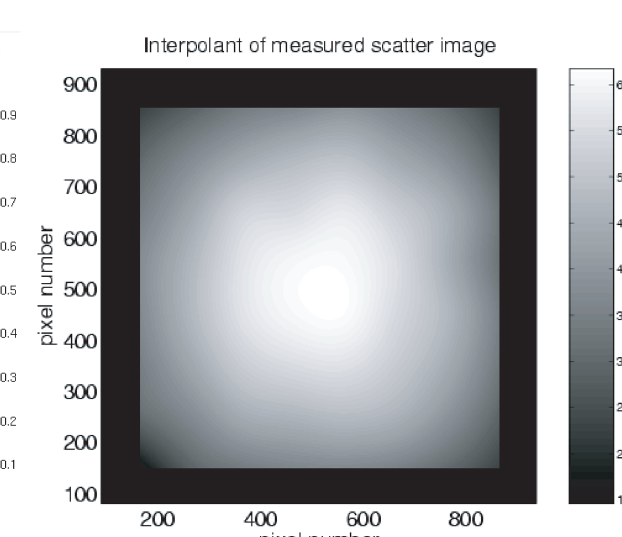
8. **Bicubic spline interpolation** of the coarse scatter image to full projection resolution yields the scatter image. This is **subtracted from the original projection** f_3.
9. After all projections are processed, they are reconstructed using a **conventional reconstruction algorithm** such as FDK.

Results

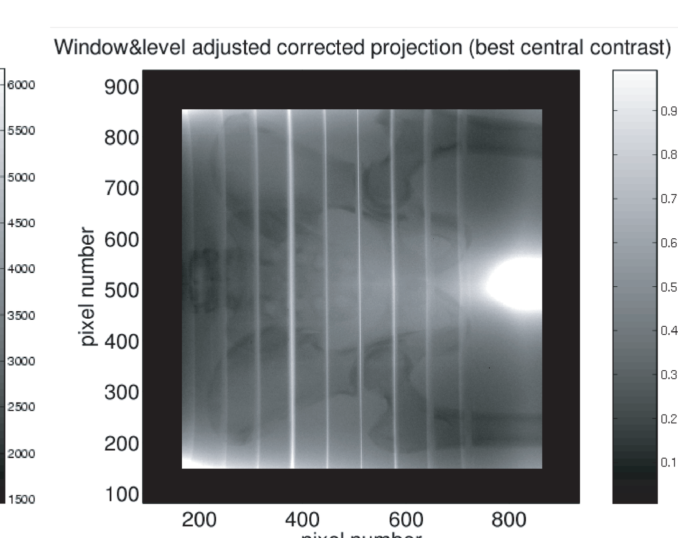
Application to a pelvis phantom imaged with 6MV beam:



Original projection image

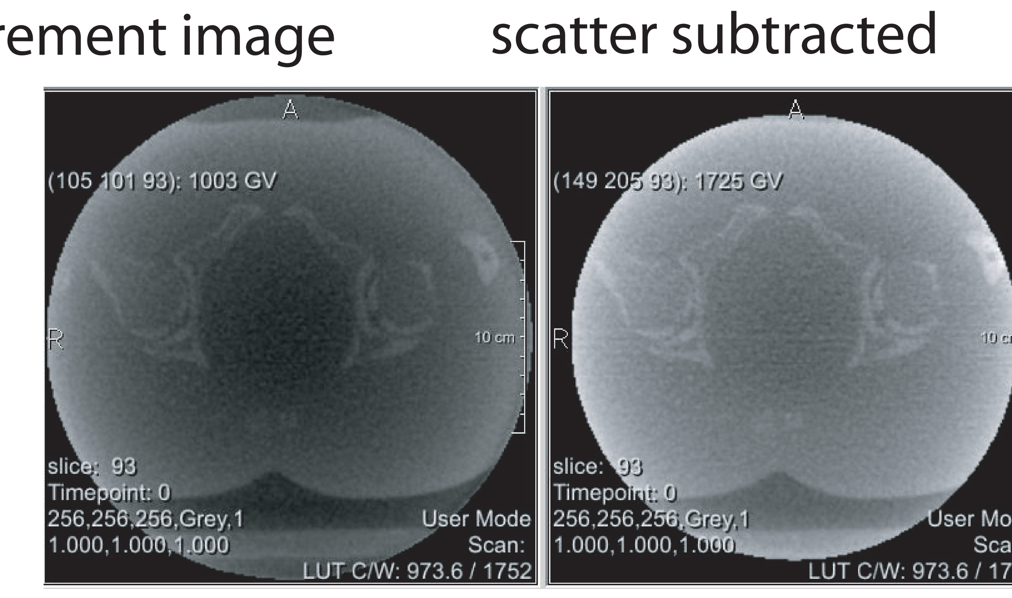


Interpolated scatter measurement image

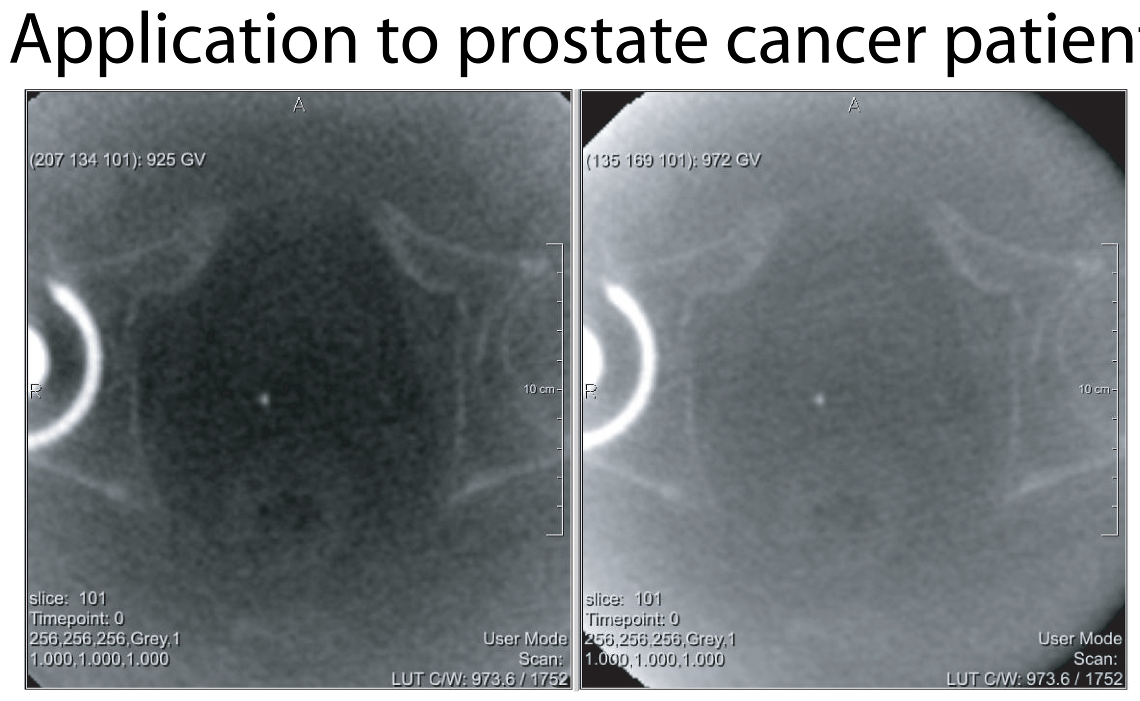


Projection image with scatter subtracted

Reconstructed MVCT data without (left) and with BSA-based scatter correction



Application to prostate cancer patient data:



A very large patient with a hip prosthesis was imaged with a 6MV linac beam with a dose of 10 monitor units (MU). Central contrast is significantly improved in corrected image (right). (Images courtesy of Dr. Jean Pouliot, UCSF.)

Conclusion

1. Beam-stop array **removes visible cupping artifact** due to scatter in phantom and patient MVCT images. The BSA performed well in a difficult application where the pelvis of a **large patient with a hip prosthesis** was imaged.
2. No extrapolation past the edge beam-stoppers was performed. The resulting truncation leads to bright ring artifacts in the FDK reconstruction.
3. The BSA is a valuable tool for scatter removal and also for validating methods of scatter estimation