Increased DQE Through Use of Light-field Cameras and Thick Scintillators in Megavoltage Imaging

B. PREUSSER[1], E. PEARSON[1], P. LA RIVIÈRE[1], and R. WIERSMA[2]
[1] The University of Chicago, Department of Radiology, Chicago, IL, United States
[2] University of Pennsylvania, Department of Radiation Oncology, Philadelphia, PA, United States

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INTRODUCTION

- The physics of high-energy megavoltage (MV) beams and the low detective quantum efficiency (DQE) of current electronic portal imaging devices (EPIDs) currently limit the clinical applicability of MV imaging in radiation therapy.
- Increasing scintillator thickness increases DQE at the expense of the spatial resolution as solid-state systems using photodiodes have resolution determined by the light spread in the scintillator.
- With the availability of prosumer light-field (LF) cameras, it is possible to capture the 4D LF emitted by a thick scintillator and refocus through the entire scintillator volume and to create an extended depth-of-field (eDoF) image in post-processing from a single LF photo acquisition.

AIM

Perform an experiment to image a 22 mm thick-monolithic and optically transparent scintillator with a light-field camera.

Evaluate refocused images against scintillator-encompassing depth-of-field conventional camera images for resolution improvements and additional beam information.

METHOD

- **Imaging Setup**
  - An LKH-5 scintillator was irradiated at 225 kVp in an XRAD 225Cx, small animal irradiator. **(Figure I)**
  - Light-field images were collected by a remotely controlled Lytro Illum.
    - Camera operation and rectification of light-field images was done with Lytro-Power-Tools software.[1] **(Figure II)**
  - A 5x5x1 mm copper square and metal and plastic based spherical CT markers were imaged by placing them on the scintillator. **(Figure III)**
- **Conventional Camera Images**
  - Images were generated from the rectified microlens array (MLA) images by selecting only the center pixels behind each lenslet to make up the image.
- **Focal Stack Generation**
  - The light-field image scene was modelled as a tomographic problem and the image volume was reconstructed using SIRT through Plenoptomos' python package.[2]

RESULTS

- **Rectified light-field images**
  - Consisted of ~ 40 million pixels (7560x5250). **(Figure II)**
  - Microlens Pitch: ~20 µm.
    - 14 x 14 pixels behind each microlens sampling the aperture results in 196 different perspective images of the scintillator from a single photo acquisition.
- **Conventional camera images**
  - Resolution was based on the number of microlenses in the MLA (540 x 375 pixels).
  - Images were equivalent to being imaged with a conventional camera with an f/16 aperture at the same distance.
  - In the copper square scene, the MTF 10% contrast cutoff was reached at 2 lp/mm. **(Figure IV)**
- **Focal stacks**
  - Resolution was based on the number of microlens in the MLA (540 x 375 pixels).
  - 14 focal slices were generated within the scintillator volume at ~ 1.6 mm intervals.
  - Refocused images were equivalent to being imaged with a conventional camera with an f/2 aperture at the same distance.
  - In the copper square scene, the MTF 10% contrast cutoff was reached at 2.25 lp/mm. **(Figure IV)**
  - In the CT markers scene, the 4 mm plastic marker came into focus at a shallower beam penetration depth than the 2 mm metal marker which came into focus in a deeper slice. **(Figure III)**
  - The LKH-5 scintillator was highly attenuating at 225 kVp. The majority of the optical photons were created in the first few mms of the scintillator. As a result, the attenuation shadows widen when refocusing deeper into the scintillator. **(Figure V)**

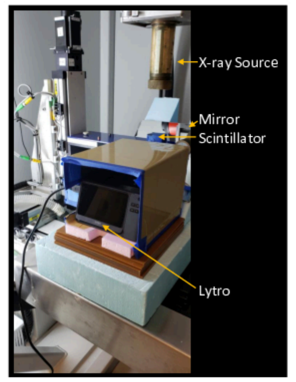


Figure I. The experimental setup inside the animal irradiator. The scintillator's optical photons were directed via mirror to the Lytro camera cased in lead.

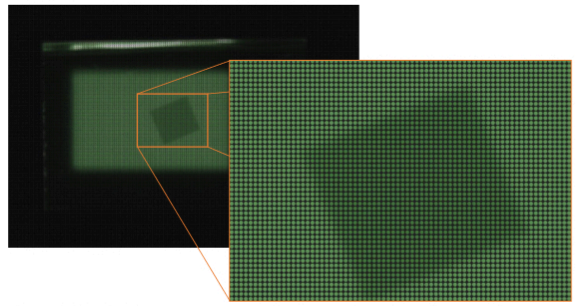


Figure II. Rectified microlens array (MLA) as produced by the Lytro Illum. Right image displays the circular lenslets that constitute the microlens array.

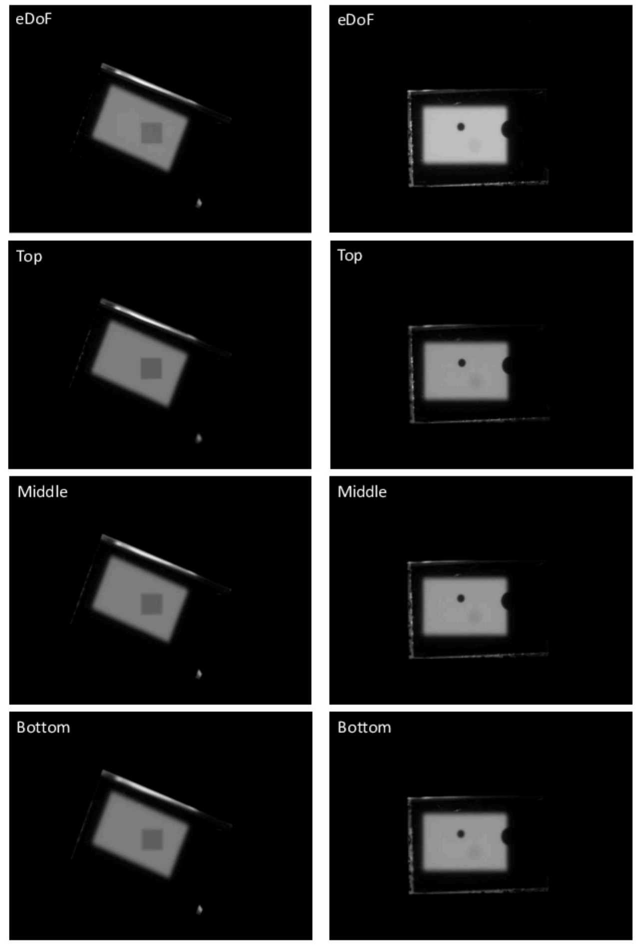


Figure III. Conventional camera eDoF scintillator image vs slices from focal stack for the copper square scene (left column) and the CT markers scene (right column). The extended depth-of-field image for each scene is shown in top row. Three focal-stack slices associated with the top, middle, and bottom regions of the 22 mm thick scintillator are shown in rows 2-4. The copper square displayed its highest sharpness when the depth-of-field was approximately centered 5 mms into the scintillator (top slice image). The 2 mm metal sphere displayed its highest sharpness when the depth-of-field was approximately centered 3.3 mms into the scintillator (top slice image). The 4 mm plastic sphere experienced its sharpest focal-stack slice at the surface.

Figure V. Images of the depth-wise cross section of the reconstructed 3D scintillator volume. The top row is the cross section through the copper square. The bottom row is the cross section through the 2 mm metal and the 4 mm plastic spheres. Arrows indicate the direction of the X-ray beam through the scintillator. The width of the right cross-section images correspond to the lines drawn in the left images. The height of the right cross-section images correspond to the number of slices in the scintillator focal stack.

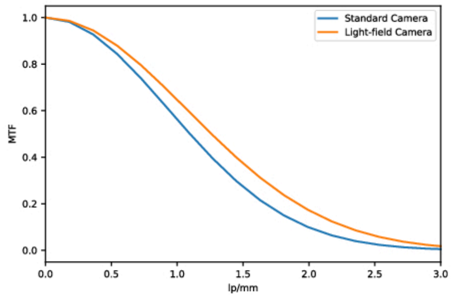
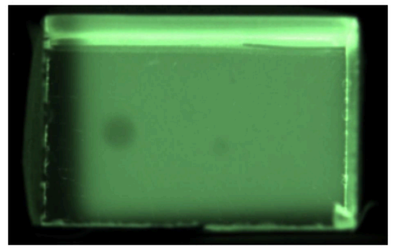


Figure IV. MTF of the sharpest copper square focal-stack slice vs a standard camera with a wide depth-of-field.

CONCLUSIONS

- The LF camera was able to capture the entire 3D scintillator volume in a single shot and was able to produce extended depth-of-field and focal-stack images of the scintillator in post-processing.
  - At 225 kVp, the LF camera provided marginally better resolution when the proper focal-stack slice was selected for comparison against the eDoF image.
- With different objects coming into focus at different depths further analysis on the information encoded within each focal-stack slice could potentially lead into information about the transmitted beam spectrum, thus potentially allowing for spectral imaging.
- Transitioning this experiment to MV energies has the potential to significantly increase the DQE in EPIDs by an order-of-magnitude as current EPIDs typically use scintillators <1 mm, whereas this LKH-5 scintillator is 22 mm. **(Figure VI)**

Figure VI. The LKH-5 scintillator at 6 MV imaging the CT markers. The left circle being the 4 mm metal sphere and the right being the 2 mm metal sphere.



ACKNOWLEDGEMENTS

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CONTACT INFORMATION

Benjamin Preusser: bmpreusser@uchicago.edu