Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Gamma imaging improvements for GrayQb™

Daniel A. Garon

Abstract. SRNL's Imaging, Robotics, and Radiation Systems Group has had several successful field deployments with the GrayQb™, a custom designed radiation mapping device. The GrayQb™ returned consistent radiation contour maps through its deployment and demonstrated its effectiveness in quickly and inexpensively capturing images of radiation hot spots. To process the images from the GrayQb™, the device must be recovered between each deployment. This is due to the GrayQb™'s use of Phosphor Storage Plates (PSPs), which are a standard X-ray imaging material in dentistry and oral applications. PSPs are highly sensitive to radiation; however, currently they must be processed through an external scanner. SRNL designed the GrayQb™ for radiation areas, and much effort is required to deploy and recover the GrayQb™. To reduce time and resources spent deploying and recovering the GrayQb™, SRNL is working to upgrade the device to read PSP images and transmit image data to an external location using an internal camera system eliminating the need to remove the PSP.

Designing the GrayQb™ internal PSP reading camera system necessitates a few primary tasks. First, the electronics and cameras that will be used in the camera system were selected. The electronics in the upgraded GrayQb™ need to be both functional and environmentally rugged. A PC/104 standard single board computer will be used to control the GrayQb™'s cameras as well as transmit the images to an external location. A Sony as7 ii and a Mightex CCD are the candidate cameras for the PSP reading camera system. Both boast high sensitivity and compact sizes. Next, a PSP image simulator was designed and characterized for quick, safe, and simple testing of the camera system. Testing PSPs with either gamma rays or X-rays is a time-consuming process.

Therefore, UV light was used to simulate a given gamma radiation dose. To standardize this simulation, the PSP was exposed to a range of UV light pulses and its behavior was characterized using a ScanX PSP scanner. The UV image simulator was then validated with radiation source image testing at SRNL's Health Physics Instrumentation Calibration Laboratory. Specifically, the PSPs were exposed to differing levels of gamma radiation from Am-241 and Cs-137 sources and the characterization was consistent with that of our simulator. Finally, the candidate cameras for our system were tested with the UV light simulator and their results were compared. The Sony camera proved to be the better option because its low noise and high resolution performance.

I. Introduction

A. GrayQb™ Single-Faced Version 2 (SF2)

The GrayQb™ SF2 (FIG. 1.) is the second generation of a custom designed Gamma radiation imaging device developed by SRNL's Imaging, Robotics, and Radiation Systems Group[1]. The device is low cost and capable of generating reliable radiation contour maps. The GrayQb™ SF2 consists of three main internal components, a Phosphor Storage Plate (PSP) to capture the radiation image, a Tungsten pinhole to direct the radiation onto the PSP, and a digital camera to capture the background image. To process and generate an image captured by the GrayQb™ SF2's PSPs, the device must be recovered from the radiation area. This process is time consuming and always presents a risk to safety. To reduce time spent and hazards risked deploying and recovering the GrayQb™, SRNL is working to upgrade the GrayQb™ to read PSPs internally and transmit the image data to an external location.

B. MiniMax (Miniature, Mobile, Agile, X-ray)

Los Alamos National Laboratory (LANL) has developed a mobile X-ray imager, MiniMax, that is capable of reading images from PSPs[2]. A PSP exposed to radiation will store energy until excited by red light. When excited, the PSP releases the energy in the form of blue light. Therefore, the MiniMax system uses a red flash mechanism to trigger the emission from the PSP and captures the released light with a commercially available DSLR camera with a blue light lens filter.

C. PSP reading camera system

SRNL has partnered with LANL to incorporate the MiniMax system into the GrayQb™ for *in situ* imaging. To accomplish this, GrayQb™ needs a camera system that is compact and capable of wireless control. In addition to reading PSPs internally, the new camera system will transmit its images to an external location. To apply the desired upgrades to the GrayQb™, we selected and implemented the hardware of PSP reading camera system, designed and validated a PSP image simulator, and compared the simulation results of two candidate cameras.

II. Realization and Testing of Upgrades

A. Hardware selection

1. Computer

The computer for the GrayQb™ upgrade was selected with the goal of building an environmentally rugged device capable of withstanding high temperatures while keeping power consumption low. We decided on using the WinSystems PPM-C407, a PC/104 industrial standard single board computer (FIG.2.). This single board computer is capable of -40°C to +85°C fanless operation and is hardened against physical and thermal shock. Additionally, the PPM-C407 runs the Windows operating system, and therefore provides a user-friendly interface.

2. Camera selection

The MiniMax system is too expensive and large for use in the new GrayQb™'s PSP camera reading system. Smaller and lower cost cameras were selected for testing. The new camera system needs to meet several main criteria. First, the new GrayQb™ needs to be inexpensive so that it may be discarded if it becomes contaminated during deployments. Second, the size of the GrayQb™ needs to be compact to fit in tight spaces such as glove boxes. A smaller camera system footprint leads to a smaller final product when the new GrayQb™ housing is realized. Third, the camera needs to be highly sensitive to image low amounts of light from the PSPs. Finally, the new GrayQb™ needs to transmit its image data to an external location. Each camera tested is capable of being controlled by the PC-104.

a) Sony a7 II

The Sony a7 II CMOS digital camera is one of the candidates for the PSP reading camera system. The Sony has a footprint of 7.5” x 5.5” x 3.5” but is still small enough for GrayQb™ applications. The Sony boasts high sensitivity with a maximum ISO of 409,000. The Sony and its lenses are available at $2,500.

b) Mightex CCD camera

The other candidate for our PSP reading camera system is the Mightex High Sensitivity CCD monochrome camera. The Mightex has a relatively small footprint at 3.6” x 2.7” x 2.7.” To read the PSP, our camera system does not need to gather color information, but high sensitivity is necessary for detecting the low amount of light from the PSPs. The Mightex is available for $1,999, a significant improvement in cost over the MiniMax.

B. UV image simulator

PSPs are designed for X-ray applications but are also sensitive to gamma radiation and UV light. UV light is the simplest, safest, and fastest method of exposure of these three; therefore, we used UV light to excite the PSPs to test our camera system. Before testing our camera system with stimulated PSPs, we characterized the PSP’s behavior by using a ScanX PSP scanner to read the PSP intensity when exposed to various levels of UV light. This characterization related UV exposure to PSP light output. Equivalent dose rates were then correlated with PSP light output from UV exposure to PSP light output from gamma source exposures. This also confirmed that the PSPs respond in a linear fashion to both UV light and gamma radiation.

1. Characterizing UV test with ScanX

First, a PSP was exposed to a specific number of UV light pulses using a UV light emitter and an Arduino Nano microcontroller. The number of pulses from the UV light could be controlled by modifying the software of the Arduino. To protect the PSP from noise caused by ambient light, the UV emitter was attached to a cylindrical covering, and the overhead lights were dimmed.

Next, the PSP was read using the ScanX PSP scanner and the average intensity of the image was recorded. The ScanX machine generated an image of the radiation captured on the PSP, and the average intensity across the PSP image was calculated using Image J, an open source image analysis software. It is important to note that the full image generated by the ScanX included not only the PSP image, but also a black border from the background. The background was generally extremely low in intensity and was ignored in the average intensity calculation.

Finally, this process was repeated 3 times using 15 different pulse numbers ranging from 5 to 100 pulses. This gave us 3 intensity values per pulse number. The PSP intensity results at each pulse were then averaged and plotted versus the number of pulses resulting in Graph 1.

This characterization provides a standard for the testing of our camera system. The characterization plot shows a linear relationship between UV exposure and image pixel intensity. Therefore, we expect similar behaviors when validating with gamma sources.

2. Validation of UV image simulator

To validate our UV image simulator, the SRS's Health Physics Instrumentation Calibration Laboratory (HPICL) was used to expose the PSPs to gamma radiation sources. At the HPIC Lab, the GrayQb™ SF2 was used to expose the PSP to different dose levels from two different sources, Am-241 and Cs-137. As with the UV image simulator, The ScanX machine was used to take images from the exposed PSPs and ImageJ was used to find the average pixel intensity of each image. Plotting the average pixel intensity versus the dose rate results in the graphs shown in Graphs 2 and 3.

Due to time constraints and the length of the effective exposure times, five images were taken with Am-241 exposure while three images were taken with Cs-137 exposure. These characterization graphs, like those of the UV image simulator, are linear which is consistent with the results from our UV image simulator. Therefore, we can confidently use the UV image simulator to test the behavior of our camera system and assign dose rate values to UV flashes.

C. Results of UV test with camera system

To test the candidate cameras, we exposed a circular PSP to UV light and obstructed the light with a steel object to store an image. As with the MiniMax system, a red flash mechanism was triggered at the time of camera exposure, and a blue pass filter was attached to the lens of the camera. To reduce ambient light, all overhead lights were shut off and a black poster board box was placed over the camera system.

1. Sony a7 ii testing

The MiniMax flash circuit can be controlled through the Sony's hot shoe connection, so it was used to trigger the PSP stimulated emission during testing.

Despite the background-reducing countermeasures, the Sony a7 ii detected significant amounts of red light. Additionally, the Sony captured stray blue light due to stray light traveling between the black box and the table. This unwanted light introduced noise into the resulting images. To isolate our radiation image, we generated a background subtracted image using the following technique: When testing the camera system, two pictures were taken: the initial PSP image and an image after the PSP had been cleared. In theory, the difference between these two images is the stimulated emission blue light captured in the initial PSP photo. Therefore, the cleared PSP image was subtracted from the initial image resulting in an image containing only the PSP UV image. This process successfully separated our radiation image and can be seen in Figure 4. The images in Figure 4.a and 4.b are the captured images while the image in Figure 4.c is the background subtracted image.

Ultimately, the Sony produced high resolution results with very low noise. Additionally, images from the PSP could be seen after only 2 UV flashes. This significantly outperforms the ScanX machine which would not produce a reliable image until approximately 10 UV flashes. Therefore, the Sony camera system should be sensitive enough for field applications.

2. Mightex testing

In the Mightex camera set up (FIG.6.), a custom designed flash mechanism was used using red LEDs, a MOSFET transistor, and a pull up resistor. A GPIO pin from the Mightex was used to trigger the gate of the MOSFET, allowing current to flow through it and turn on the red LEDs.

The Mightex detected the following images at 100, 50, and 10 flashes from the UV simulator. The images were significantly noisier than the Sony images. The images from the PSP could not be seen until approximately 10 UV flashes were applied. 50 flashes also produced very noisy images.

III. Conclusions

Ultimately, we confirmed that our camera systems can read images from PSPs. Additionally, from the Sony we could see a PSP image after only 2 flashes from the UV light, which outperforms the ScanX PSP reading machine. On the other hand, the Mightex camera struggled to obtain images at even 10 flashes and produced very noisy images overall. Its compact size made it an attractive candidate, but its performance was not high enough to recommend for the GrayQb™ upgrades.

The next steps include designing a housing for the PSP reading camera system. A housing needs to be realized that is compact and capable of holding the PC/104 and its peripheral devices, the Sony-based PSP reading system, and the digital camera used to take an environmental background photo. Once the housing is realized, the entire system will be tested at the HPICL, and its performance will be evaluated.

IV. Acknowledgements

This project was funded by the DOE Office of Science through the SULI program.

Special thanks to mentors and managers Donald Benza, Jean Plummer, and Richard Minichan for support and guidance.

Figures

FIG.1. GrayQb™ Single-Faced
Version 2

FIG.2. PC/104 standard single board
computer.

FIG.3. PSP simulator setup. From left to right: ScanX PSP Reader, Arduino Nano, UV light attached to cylindrical covering

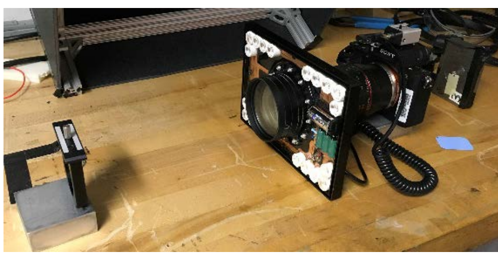


FIG.4.a

FIG.4.b

FIG.4. Sony a7 II camera system setup including MiniMax flash mechanism and circular PSP

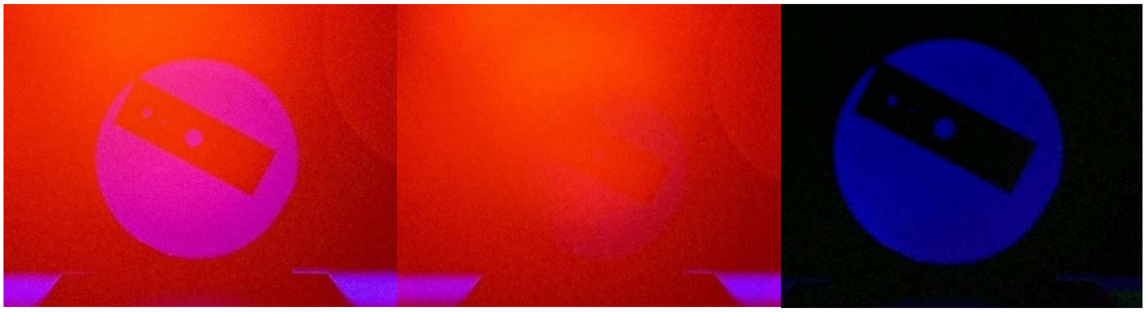


FIG.5.a FIG.5.b FIG.5.c

FIG.5. PSP image captured from Sony a7 ii camera system. (a) initial image (b) background image (c) background subtracted image

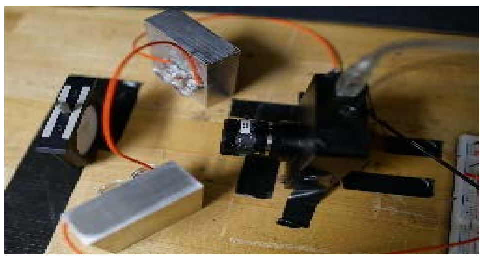


FIG. 6. Mightex camera system with red LEDs and circular PSP.

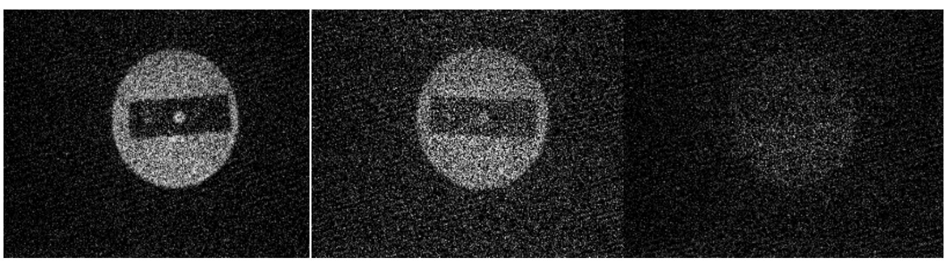
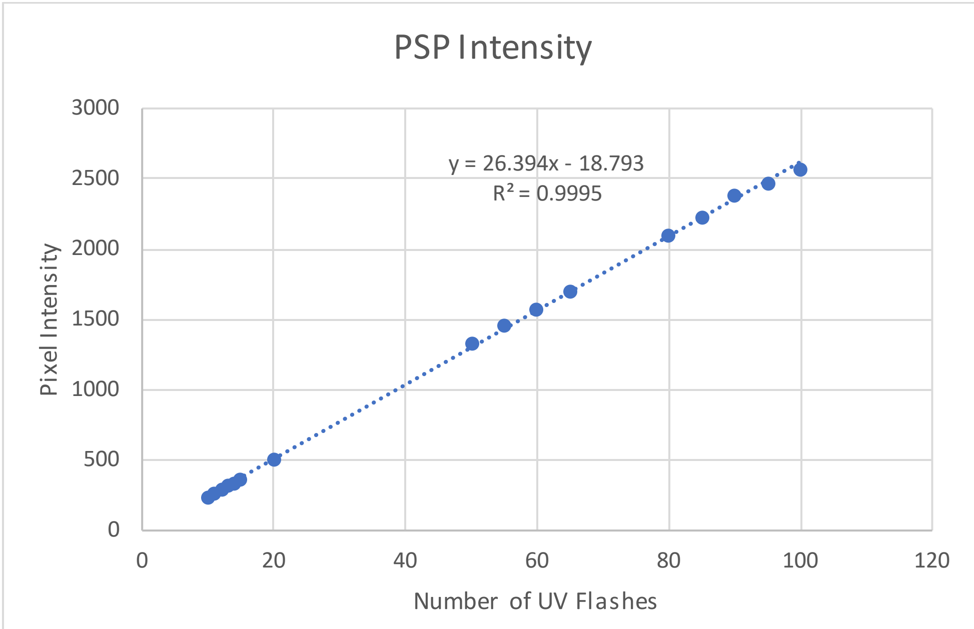


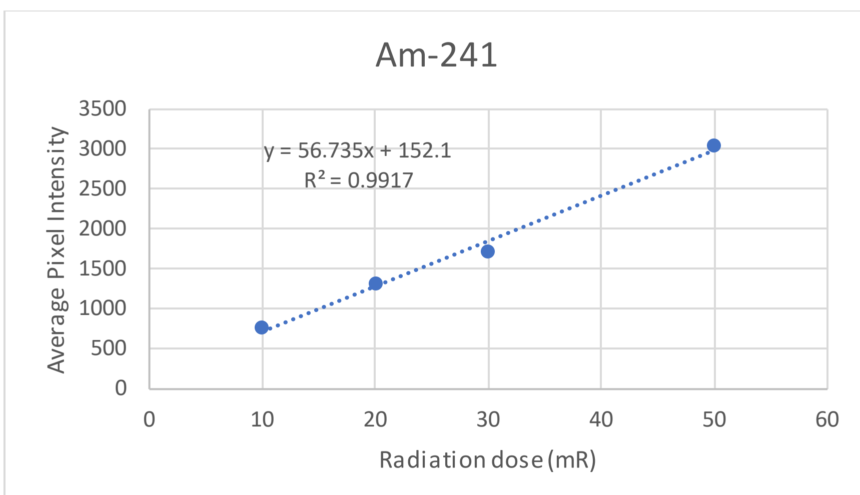
FIG.6.a FIG.6.b FIG.6.c

FIG.6. PSP images captured from Mightex camera system. (a) 100 Flashes (b) 50 Flashes (c) 10 Flashes

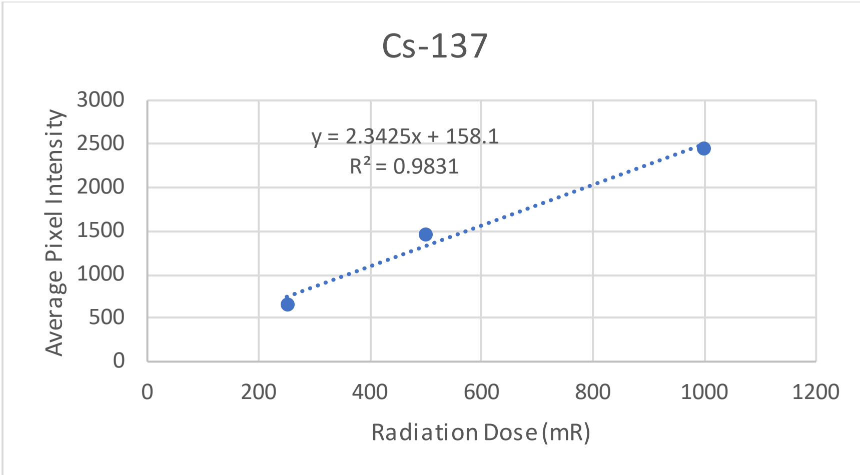
Graphs



Graph 1



Graph 2


Cs-137
y = 2.3425x + 158.1
R² = 0.9831
Average Pixel Intensity
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Radiation Dose (mR)

Graph 3

References

[1]J.R. Plummer, D. M. Immel, J.T. Bobbit, M.J. Negron, "GrayQb™ Single-Faced Version 2 (SF2)," SRNL-TR-2014-00216 (2015).

[2]Scott A. Wilson, Gwynneth Cunningham, Samuel Gonzales. "MiniMax: miniature, mobile, agile, x-ray system," Proceedings of the SPIE, 8371 id. 83711E-83711E-7 (2012).