Experimental investigation of gamma radiation effects on CCD cameras

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Introduction

Silicon based imaging cameras based on Charge Coupled Devices (CCDs) are used for various applications in space and nuclear facilities. These cameras suffer degradation of imaging quality due to radiation damage caused by charged particles such as protons, heavy ions and other radiations such as neutrons, gamma, etc. The ionizing radiations such as gamma mainly creates surface damage at the Si/SiO_2 interface whereas heavy charged particles and neutrons create displacement damage in the silicon [1]. The displacement damage results in the generation of electronic trapping centers with energy levels in the bandgap of silicon. CCD cameras are used for remote handling operations in high radiation zones such as hot cells and hence their radiation hardness is a critical parameter. In this paper, we have examined the degradation behavior of two CCD cameras irradiated using a Co-60 source in a hot cell at a constant dose rate. The degradation of the imaging quality of the cameras has been analyzed using acquired images during the irradiation. The experimental details and results are presented in the subsequent sections of this paper.

Experimental

Two CCD cameras, manufactured by M/S Bosch and M/S Samsung, were irradiated at a constant dose rate of 6 krad/hr using Co-60 source in the hot cell of FIPLY facility of Bhabha Atomic Research Centre. These cameras are referred as CAM1 and CAM2 hereafter. The specifications and other details of the cameras are presented in Table 1. The cameras from different manufacturers were selected in order to see the effect of fabrication technology on radiation-induced degradation of the cameras. Both the cameras were focused on a test scene. The test scene was designed to assess the image quality degradation, and it comprised of various types of patterns of black and white boxes, strips, etc. During the experiment, the dose rate at the camera location was measured using a chemical dosimeter. Both the cameras were kept under bias condition and continuous videos were recorded with a digital video recorder. Hence, the output videos included the effect of total dose damage as well as transient currents generated due to the gamma radiation. Using the data acquired, the degradation of the imaging quality was analyzed offline using image analysis techniques.

Table 1: Specification of CAM1 and CAM2.

Parameters	**CAM1**	**CAM2**
Make	Bosch	Samsung
Model No.	LTC 0455/51	SCB-1001P
Sensor	1/3" CCD	1/3" CCD
Output	Analog	Analog
Resolution	540 TVL	600 TVL

Result and Discussion

Pre-rad and post irradiation images from CAM1 (Make: Bosch) and CAM2 (Make: Samsung) are presented in Fig. 1 (a) and (b), and Fig 2 (a) and (b) respectively. As can be seen, the pre-rad images were of good visual quality. During gamma radiation exposure, snow effects appeared in the images acquired from both the cameras. This snow effect was because of the generation of electron-hole pairs in photosensitive region of camera sensor due to the gamma radiation. This is a transient effect which is present only during gamma exposure.

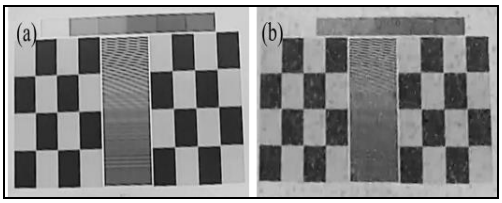

Fig. 1: Images from CAM1; (a) Pre-rad, (b) After TID of 25 krad.

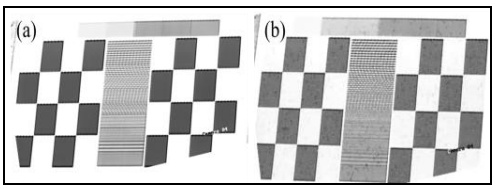

Fig. 2: Images from CAM2; (a) Pre-rad, (b) After TID of 22 krad.

As seen from Fig 1(b), visually, the image quality for CAM1 was found to be slightly degraded. However, it was found that the camera abruptly failed at 25 krad of total ionizing dose (TID) with a message of "No Video" on the monitor. The abrupt failure of this camera could have been due to either failure of readout circuitry or due to the failure of power supply of camera because of the radiation damage. As shown in Fig. 2(b), visually, CAM2 showed higher degradation of the image quality compared to CAM1 with the decrease in the contrast of image at TID of 22 krad. The camera failed at higher doses showing an abrupt appearance of a black image on the screen. The image analysis of the black images showed that the signal in the image pixels was very small indicating the possible failure of the amplifier circuit.

To quantify the degradation of image quality of both the cameras, image parameters such as mean pixel value, peak signal to noise ratio (PSNR), contrast and structure similarity index matrix (SSIM) of the images were calculated [2]. The variation in the mean value of pixels of an image with TID is an indicator of increase in the dark signal. The variation in the PSNR value gives the deviation of the post radiation image from its original pre-rad image with respect to the peak signal value i.e. 255 for 8-bit resolution images. The SSIM is a multiplication of three components: luminance, contrast and structure. The changes in these parameters before and after gamma irradiation are tabulated in Table 2. As can be seen from Table 2, the percentage change of the image parameters with respect to pre-rad parameters are higher for CAM2 than CAM1 indicating higher degradation of CAM2. The final failure of both the cameras was due to the failure of associated electronic circuitry. The TID at which the electronic circuits fails depends on circuit design, threshold values, design margins, etc. Hence, the cameras from different manufacturers exhibited failure in different associated circuitry.

Table 2: Percentage change in the image parameters with respect to pre-rad image parameters.

Parameters	**Camera 1**	**Camera 2**
Mean pixel value	-0.80658	-1.191
PSNR	-4.77781	-15.9164
Contrast	-0.47117	-2.59947
SSIM	-1.36561	-5.5255

Conclusions

We have experimentally studied the Co-60 gamma radiation-induced degradation of two cameras from two different manufacturers. Both the cameras showed degradation of the image quality. However, the mode of failure was observed to be different for the cameras. The image quality degradation was quantitatively estimated using parameters such as mean pixel value, PSNR, contrast and SSIM. The quantitative image analysis techniques presented in this paper could be useful for the selection of cameras and estimation of radiation hardness for deployment in high gamma radiation environments.

References

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