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NCNR National Centre for Nuclear Robotics

Measuring the Degradation of Commercial Cameras Under Fast Neutron Beam

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Introduction

- The main bottleneck to the access of extreme environments (such as nuclear sites) comes in the form of the health risks associated with different forms (neutron, gamma) and levels (flux, dose rate) of radiations.
- Robotic system emerges as an ideal solution
- The role of vision sensors (RGB-D and stereo cameras) in this regard is pivotal to assist the robot navigation.
- The radiation rich environments jeopardize the reliability of the vision sensors by causing :
    - o Transient Damage (Single Event Effect (SEE))
    - o Permanent Damage (Displacement, Ionization)

Introduction

- The radiation hardened camera sensors could be a solution however, the trade-off is their excessive cost.

- Low cost, ease of use, compact size, and compact data storage make COTS digital camera ideal for robots.

- In this perspective, one of the key research directions is to

Analyse the effect of different types of radiations on COTS image sensors.

Aims & Objectives

- Evaluate and compare the sensor degradation of two popular commercial CMOS-based cameras, namely Raspberry Pi camera and Trust USB camera, as a function of exposure time in the presence of neutron beam.
- Evaluate the evolution of the transient and permanent pixel damage in the cameras during the radiation cycle.
- Evaluate the recovery of the permanently damaged pixels during the annealing period.

Experimental Setup

- Radiation experiments were conducted with neutron beam at the ChipIr facility at ISIS, RAL, Didcot, Uk.

- Both the cameras were tested for about 12 hours that amounts to a neutron yield of 2.3×10^{11} considering a 3.5 cm x 3.5 cm beam.

- Dark images were captured from the cameras during the experiment by covering their apertures with black tape.

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Experimental Setup

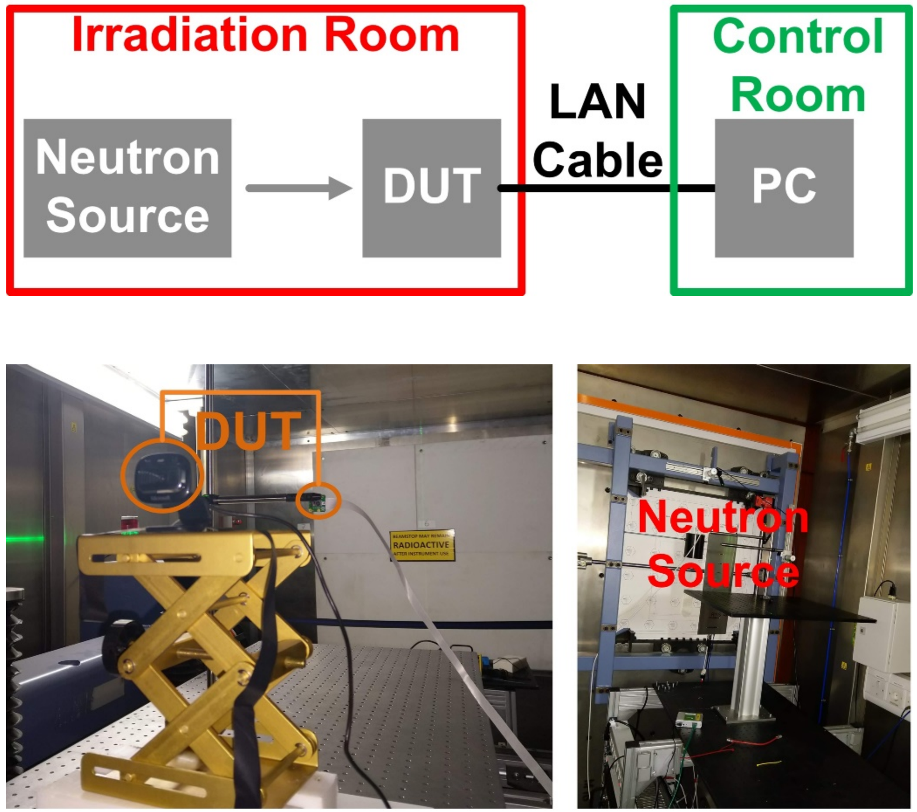

Figure 1. Experimental Setup at ChipIr, RAL

Evaluation Methodology

- **Detecting Damaged Pixels**
  - Without radiations pixels values are normally distributed and thus all the pixels values should remain under the threshold value of $\mu+3\sigma$.
  - Under radiation effect, this pixel distribution spreads out and thus pixel with intensity levels greater than the threshold values are identified as damaged pixels.
  - **Pixel Damage Factor (PDF)** is the ratio of the *number of damaged pixels* to the *total number of pixels*.
- **Detecting Permanent and Single Event Effects (SEE)**
  - An algorithm is proposed to categorize the pixel damage as permanent or SEE.

Evaluation Methodology

Algorithm 1: SEE and Permanent Damage Detection:

1. **Input:** Radiated images with time stamps.
2. **Output:** Detection of Single Event Effect and Permanent Effects.
3. **Begin**
4. ***for*** each input radiated image ***do***
5. Detect the damaged pixel in the image with time stamp t;
6. Store the pixel positions in a list L_t
7. ***end for***
8. Consider two consecutive lists L_t *and* L_{t+1}; */* where* L_{t+1} *denotes the list created from image with time stamp* $t+1$ **/*
9. ***if*** a pixel appears in both the lists ***then***
10. This damage in camera will be considered as a Permanent or displacement damage;
11. ***else***
12. The damage is considered as transient (SEE)
13. ***end if***
14. **End**

Results & Analysis

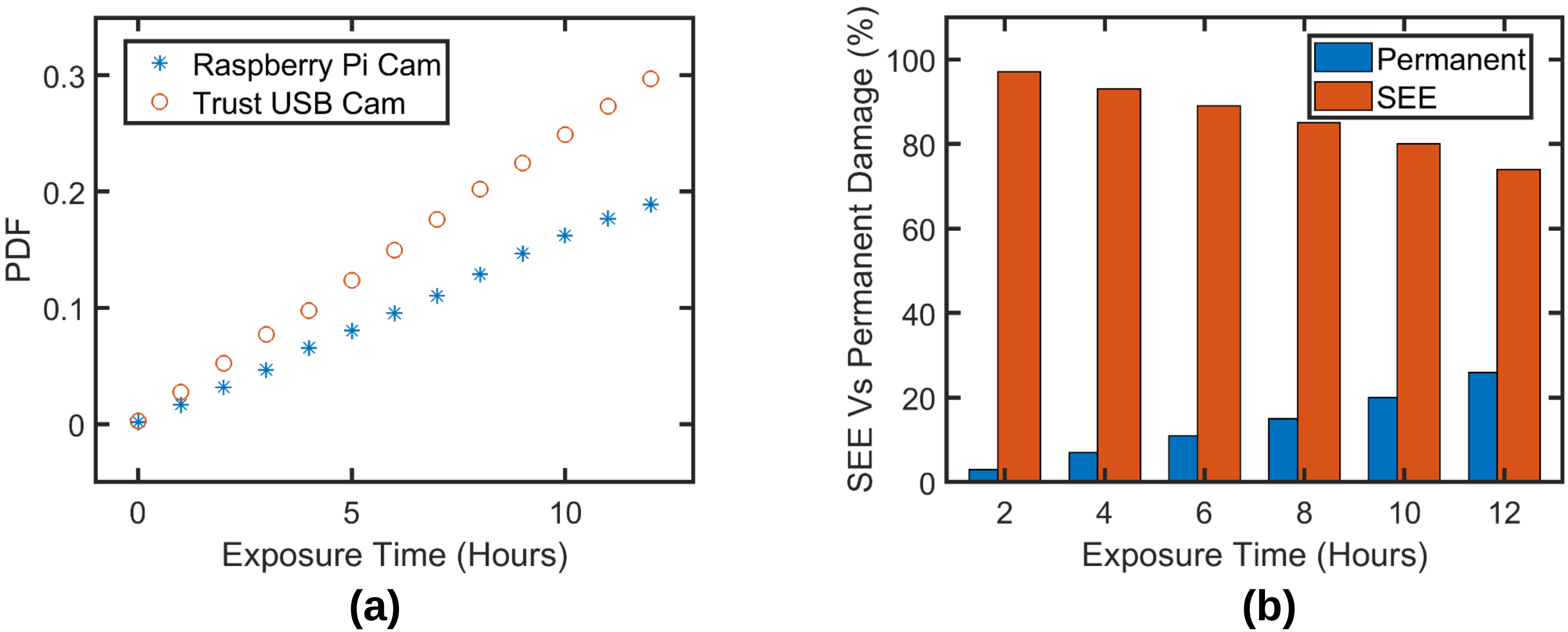

Figure 2. (a) PDF plot of camera sensors, and (b) Evolution of SEE and Permanent pixel damage during exposure cycle

Results & Analysis

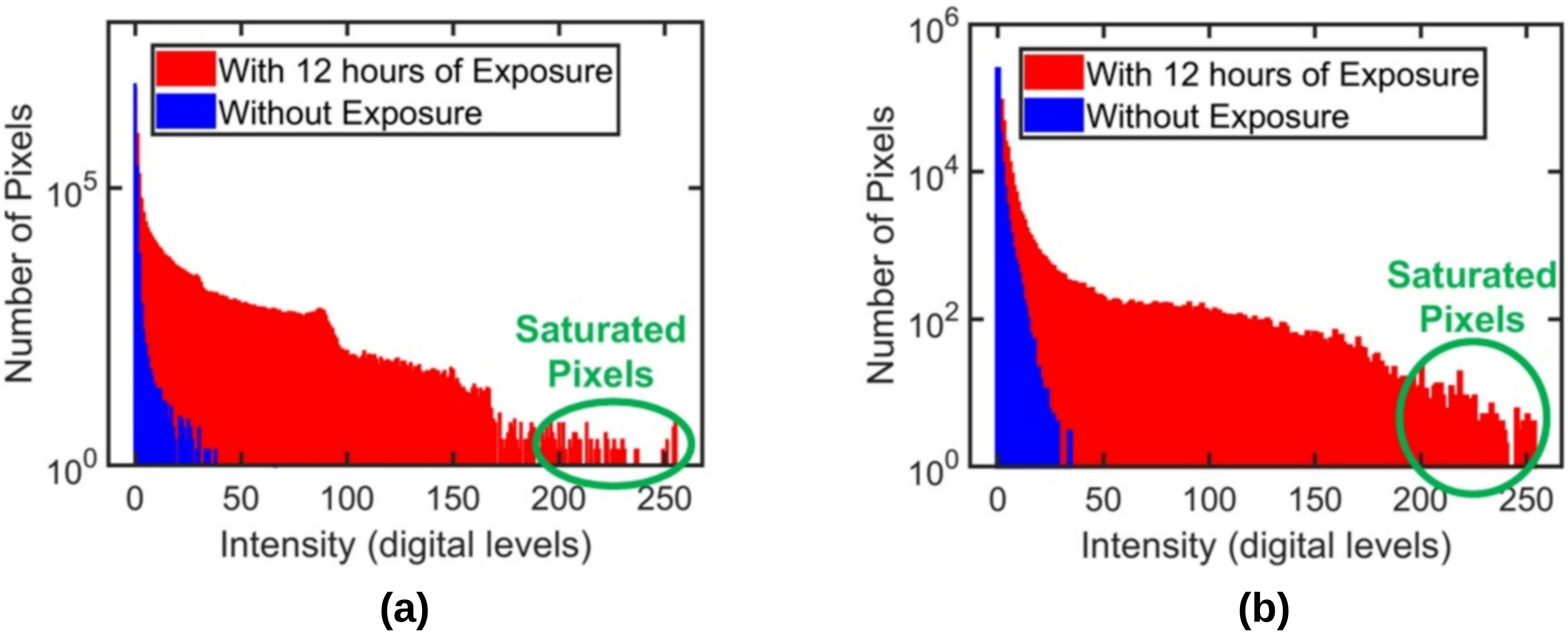

Figure 3. Dark Image Histogram of : (a) Raspberry Pi Cam, and (b) Trust USB Cam

Results & Analysis

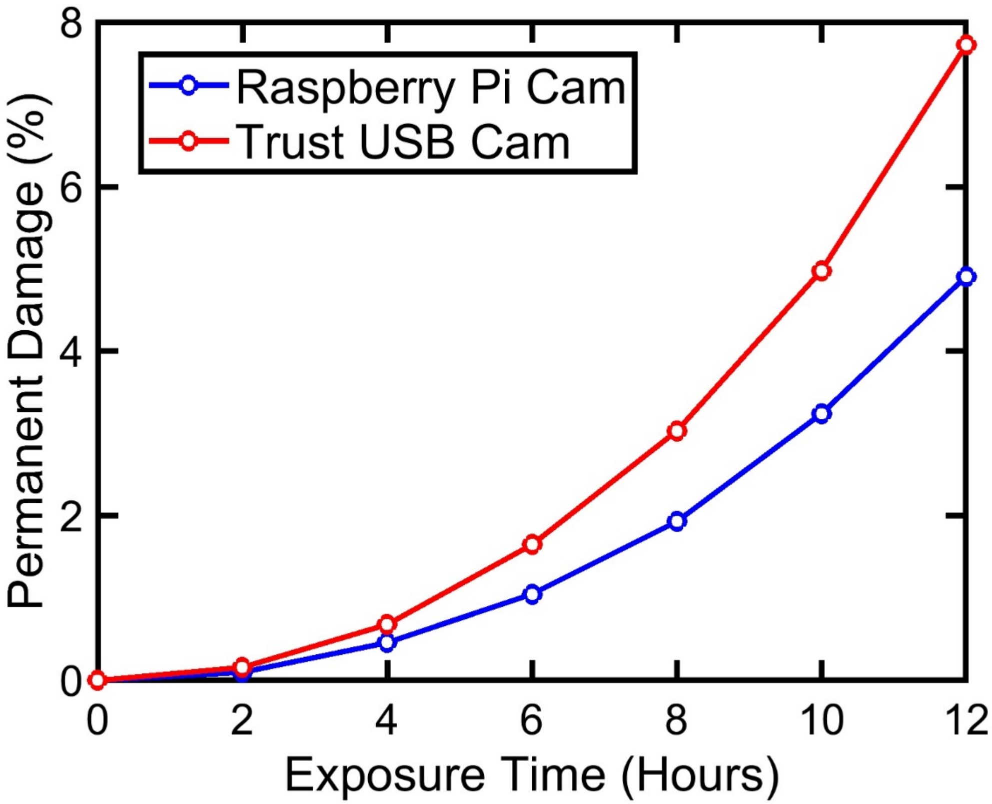

Figure 4. Permanent pixel damage during exposure cycle

Results & Analysis

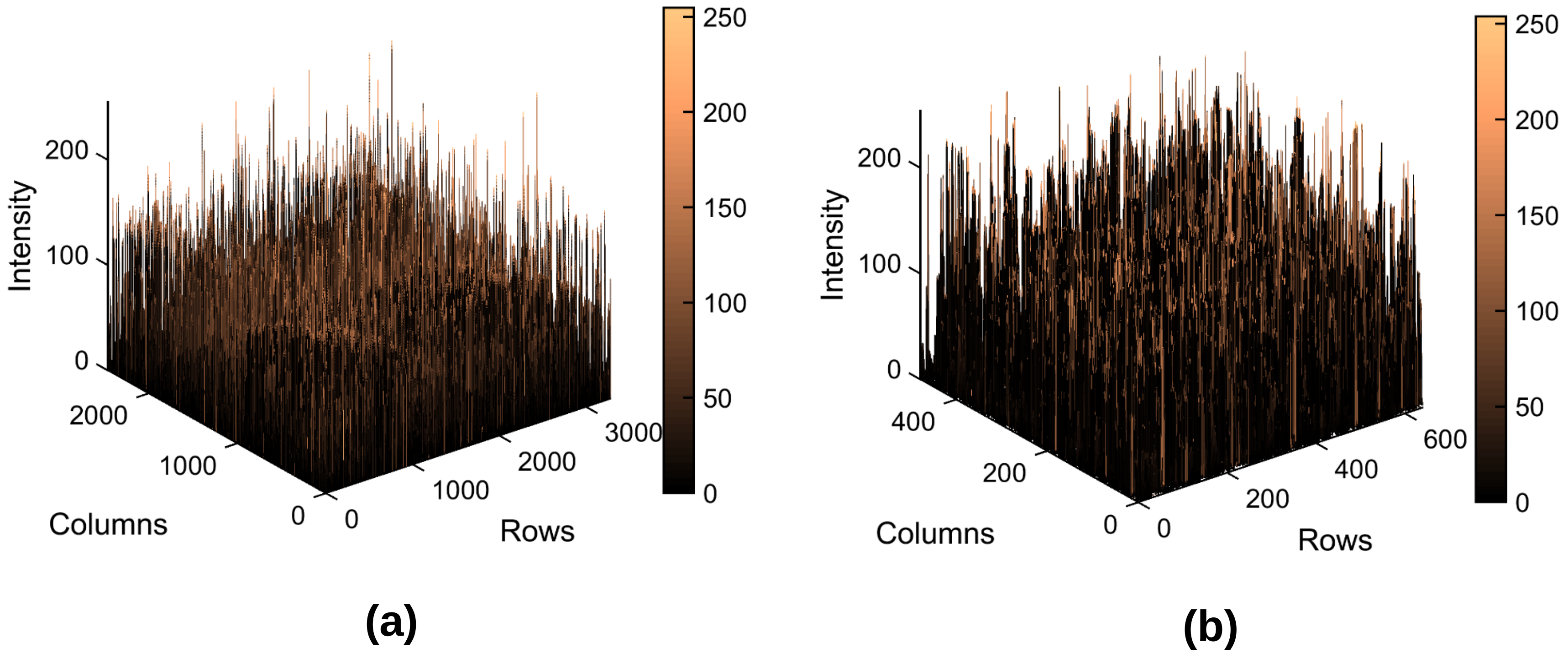

Figure 5. 3D surface distribution plot after 12 hours of neutron exposure of: (a) Raspberry Pi Cam, and (b) Trust USB Cam

Results & Analysis

Table 1. Damaged pixels recovery during the annealing cycle

Annealing Time (Hours)	Recovered Pixels (%)	
	Raspberry Pi Cam	Trust USB Cam
3	2.5	2
6	4	3.5
9	4.8	4
12	5.2	4.3

Conclusions

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- Results show that the degradation rate of Raspberry Pi cam sensor is 40% lower than the Trust USB camera.
- The number of permanently damaged pixels increase linearly over the exposure time.
- No significant healing of the pixel damage is observed for either cameras.

Future Directions

- Perform similar experiments for the gamma radiations and compare the results.
- Measure image sensor parameters such as dark current, dark signal non-uniformity, read noise, peak response non-uniformity, and signal to noise ratio under the neutron beam.
- Come up with noise models to relate the sensor parameters degradation with the radiations (neutron fluencies/gamma doses).


Thank You!