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Monitoring Index of the Cameras during the High Dose-Rate Gamma Ray Irradiation

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1. Introduction

When we examined TEPCO's Fukushima Daiichi nuclear power station unit 3 reactor building basement torus room investigation video [1], we found dozens of speckles in the entire image frame. Generally, speckles occur in a CCD/CMOS image when the CCD/CMOS camera is exposed to high dose gamma ray source. In the above torus room investigation image by the Survey Runner robot system, the gamma ray dose-rate was about 100mSv/h. The dozens of speckles in the entire image (640×480) are not obstacles to examine the unit 3 reactor building basement torus room situation closely. Analyzing other videos, as a second investigation inside the primary containment vessels (approx. 500~1000mm inside of the internal wall) in the unit 2 reactor of the Fukushima Daiichi nuclear power station using an industrial endoscope [2], dense speckles were observed in the investigation image. The gamma ray dose-rate was 30~70 Sv/h at the measurement location. The overwhelming number of speckles in the investigation image are a hindrance to scrutinize the inside situation of the primary containment vessels of the unit 2 reactor.

The CCD/CMOS cameras, which are loaded on the robot system, are generally used as the eye of the robot and monitoring unit. A major problem that arises when dealing with images provided by CCD/CMOS cameras under severe accident situations of a nuclear power plant is the presence of speckles owing to the high dose-rate gamma irradiation fields. To use a CCD/CMOS camera as a monitoring unit in the high radiation area, the legibility of the camera image in such intense gamma-radiation fields should therefore be defined. In this paper, we describe the monitoring index as a figure of merit of the camera's legibleness under a high dose-rate gamma ray irradiation environment. From the low dose-rate (2.11 Gy/h) to the high dose-rate (200 Gy/h) level, the legible performances of the cameras owing to the speckles are evaluated. The numbers of speckles, generated by the gamma ray irradiation, in the camera image are calculated by an image processing technique. The relation between the legibility of the camera image and the numbers of speckles is also presented.

2. Experiments

A typical experimental setup of gamma ray irradiation for the CCD cameras is shown in Fig. 1. The CCD cameras of various types were gamma irradiated at a dose rate of about 200 Gy/h until these cameras failed. And the distance between the target (CCD sensor) and the gamma ray source (Co-60) is 13.7cm. As shown in Fig. 1, the CCD sensor takes a front view of the resolution target to the rear of the gamma ray source.

Fig. 1 Various CCD cameras take a front view of the gamma ray source (Co-60).

To evaluate the on-line performance of various cameras simultaneously, as shown in Fig. 1, a 4 channel video multiplexer is used. After about 43 minutes elapsed, two B/W CCD cameras (yellow sheet as stuck on the top of the camera body, as shown in Fig. 1) failed at a 143 Gy (TID) dose. The other two B/W CCD cameras survived after about a 74 minute irradiation dose (246 Gy TID). The manufacture year of the two failed CCD cameras is 1998. And the other two surviving CCD cameras were fabricated in 2001. A digital still camera (manufactured in 2004) positioned at the rightmost side of Fig. 1 also failed after the same dose (246 Gy TID).

Table 1. Active devices on the CCD camera control board.

CCD Camera (Year)	Distance (mm)[*1]	Active Devices (Number of control boards)
SFA-410ED (1998) Failed	30	CXA1310AQ 1406F0050 (64 pin) CXD1265R (5 boards)
TM-7CN (2001) Survived	25	CXD 1250 64 pin ASIC Chip (2 boards)
XC-75CE (2001) Survived	30	CXD 1250 CXD 1256AR CXA 1310AQ 48 pin ASIC Chip (3 boards)
DSC-V1 (2004) Failed	2	8 active devices including JSSDP356A32S are placed on the single board.

[*1] Distance between image sensor and nearest active device

We did not consider the placement of passive devices (capacitor, resistor and inductors) because such devices are more radiation-hardened than active devices [3]. The distance item, shown in Table 1, means the

distance between the image sensor and nearest active device placed on camera control board. In the case of SFA-410ED, the image sensor is 13.7cm (200 Gy/h) away from the gamma ray source and the active device is 16.7cm (about 170 Gy/h) apart from the gamma ray source. From the comparison results of the SFA-410ED, TM-7CN, and XC-75CE camera models, it is estimated that an enhancement of the ASIC FPGA fabrication process and a more sophisticated design of the camera control circuit improve radiation hardness under a similar dose rate. Table 2 shows the number of speckles and the monitoring index of CCD/CMOS cameras according to the gamma ray dose-rate. A monitoring index $\mathbf{M_F}$ is defined as the following equation.

$$M_F = \frac{N_S}{I_p} \times 100 \qquad (1)$$

In equation (1), N_s is the number of speckles, and I_p is the number of pixels of the CCD image sensor. The number of speckles in the entire CCD image is calculated using an image processing technique (background subtraction) .

Table 2. Speckle numbers and monitoring index of CCD/CMOS cameras according to gamma ray dose-rate

Camera (Model) (Year)	Dose Rate (Gy/h)	Pixels	Speckles	Index
Color CCD (FCB-IX) (2008)	2.11	307200	134.63	< 1 (0.04)
Color CMOS (WEB) (2001)	3.4	76800	1030.13	1.34
	18	76800	17863.40	23.26
Color CCD (EVI-D100) (2004)	150	307200	40933.66	13.32
Color CCD (Pin Hole) (2012)	150	267360	72722.70	27.20
Color CCD (Cylinder) (2006)	150	345600	86172	24.93
BW CCD (Board) (2004)	120	345600	57711.32	16.70
Color CMOS (Black Box) (2009)	150	307200	70167.79	22.84
BW CCD (SFA-410) (1998)	200	76800	13788.07	17.95

A monitoring index of a CMOS web camera as shown in Table 2 is 23.26 at a 18 Gy/h gamma ray dose rate. Figure 2 shows an LCD panel monitoring image of a thermo/hygrometer using a CMOS web camera under an 18 Gy/h gamma ray dose rate condition. Generally, the setup time of the gamma ray source from the basement storage shelter to the irradiation position is about 10 seconds.

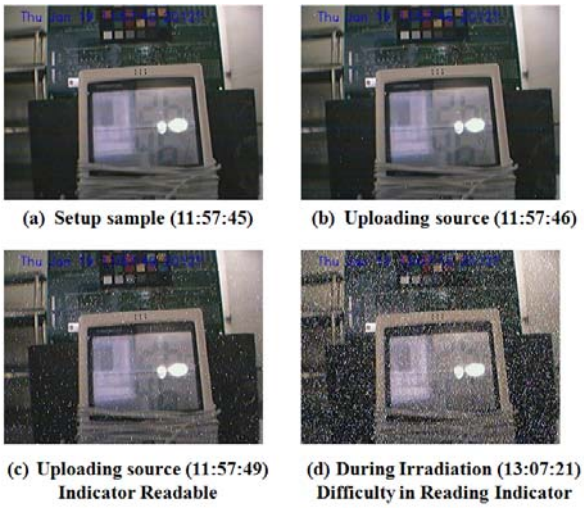

Fig. 2 LCD panel monitoring image of thermo/hygrometer using a WEB camera under gamma ray irradiation (18 Gy/h)

As shown in Fig. 2(d), when the monitoring index of the CMOS web camera is bigger than 20, it is not easy to read the LCD panel display number of the thermo/ hygrometer. In the case of Fig. 2(b) and Fig. 2(c), the numbers of speckles are 136 and 3199, respectively, and the monitoring index is 0.18 and 4.17. Therefore, it is legible to easily read the LCD panel display digit of the same instrument because the gamma ray dose rate is low during the setup time of the gamma ray source.

3. Conclusions

We conducted high dose-rate (2.11~200 Gy/h) gamma ray irradiation experiments on CCD/CMOS cameras, estimated as being used as the eye of the nuclear emergency response robot and the visual inspection unit. The heavily generated speckles from the high dose-rate gamma ray are obstacles to scrutinize nuclear structures under a high radiation environment. From the above experimental results, we proposed a monitoring index as a figure of merit of the camera's legibility under a dose-rate gamma-ray irradiation environment. In the case of a CMOS camera, when the monitoring index is bigger than 20, it is not easy to read the LCD panel display number of the thermo/ hygrometer.

[1] TEPCO, "Fukushima Daiichi Nuclear Power Station Unit 3 Reactor Building Basement Torus Room Investigation", July 2012, http://www.tepco.co.jp/nu/fukushima-np/
[2] TEPCO, "Result of the dose measurement in the second investigation inside of Primary Containment Vessels, Unit 2, Fukushima Daiichi Nuclear Power Plant", March 2012, http://www.tepco.co.jp/nu/fukushima-np/
[3] P.C. Bennett, "RHOBOT: Radiation Hardened Robotics ", SAND97-2405, October 1997