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An investigation of medical radiation detection using CMOS image sensors in smartphones

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ABSTRACT

Medical radiation exposure to patients has increased with the development of diagnostic X-ray devices and multi-channel computed tomography (CT). Despite the fact that the low-dose CT technique can significantly reduce medical radiation exposure to patients, the increasing number of CT examinations has increased the total medical radiation exposure to patients. Therefore, medical radiation exposure to patients should be monitored to prevent cancers caused by diagnostic radiation. However, without using thermoluminescence or glass dosimeters, it is hardly measure doses received by patients during medical examinations accurately. Hence, it is necessary to develop radiation monitoring devices and algorithms that are reasonably priced and have superior radiation detection efficiencies. The aim of this study is to investigate the feasibility of medical dose measurement using complementary metal oxide semiconductor (CMOS) sensors in smartphone cameras with an algorithm to extract the X-ray interacted pixels. We characterized the responses of the CMOS sensors in a smartphone with respect to the X-rays generated by a general diagnostic X-ray system. The characteristics of the CMOS sensors in a smartphone camera, such as dose response linearity, dose rate dependence, energy dependence, angular dependence, and minimum detectable activity were evaluated. The high energy gamma-ray of 662 keV from Cs-137 can be detected using the smartphone camera. The smartphone cameras which employ the developed algorithm can detect medical radiations.

1. Introduction

The use of radiation in medicine has increased annually with the improvements of medical imaging devices such as general radiographic X-ray equipment, X-ray fluoroscopy, computed tomography (CT), single photon emission computed tomography (SPECT), and positron emission tomography (PET). As a result, the radiation exposure doses for patients and medical staff have also increased, which could potentially be hazardous for the health of both patients and staff. For these reasons, the medical radiation exposures to patients and staff should be monitored and managed carefully to prevent the potential health hazards. On top of that, the awareness of radiation danger has also increased dramatically since the nuclear accidents at Fukushima, Japan in March 2011.

Consequently, the concerns of medical radiation exposure and nuclear reactor accidents have increased the demand of a personnel dosimeter which can be used easily at a reasonable price.

The Geiger–Müller (G–M) counter has been used widely as a survey metre to measure radiation exposure dose in hospital and industrial field. However, it is not affordable to be used as a personal dosimeter, because the GM counter is bulky and expensive. Besides the limited number of GM counters makes it difficult for public to use the GM counter as a personal dosimeter.

The scintillation detector which uses a combination of a scintillator and semi-conductor detector, can provide an excellent detection efficiency for high energy gamma rays with energy information. Despite the fact that the scintillation detector can be manufactured in a small size while maintaining the excellent performances, it is unaffordable to public due to the expensive price.

On the other hand, the complementary metal-oxide semiconductor (CMOS) image sensors of smartphone cameras can detect not only visible light but also ionizing radiations such as ultraviolet ray, X-ray, and high energy gamma-ray [1–3]. The

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potential of smartphone camera as a gamma-ray detector has been demonstrated and the application software called GammaPix was developed [4]. Also the usability of smartphones for dose alerts was investigated with an android application software called Radioactive Counters [5,6].

The smartphones have become ubiquitous rapidly throughout the world. The performances of smartphone camera, such as camera pixel depth, camera frame rate and computing speed also have been accelerated, which makes it easier to extract and analyze X-ray informations obtained by smartphone cameras.

In order to use smartphones as a radiation warner, the radiation responses of the smartphones should be characterized carefully [7]. We developed an algorithm to extract and characterize radiation induced pixel intensity from the thermal noise of the CMOS sensors in smartphones. The aim of this study is to investigate the feasibility of smartphone CMOS image sensors as a radiation warner for medical radiation, such as X-rays and gamma rays.

2. Experimental set-up

2.1. X-ray detection using CMOS image sensors in smartphone

The smartphone camera was wrapped with black tape to allow the CMOS image sensor of the front camera to interact with X-rays and gamma-rays while blocking visible light rays. The Galaxy S2 smartphone (Samsung Electronics, SHW-M250S, South Korea) was operated in a video recording mode while the smartphone camera was irradiated by X-rays switched on 10 s after the video recording has started using a diagnostic general radiographic X-ray system (Choongwae Medical, CXD-RI55, South Korea) as shown in Fig. 1. The anode angle of the tungsten target was 17°. The intrinsic filtration was 2 mm thick aluminium and additional filtration was 1.0 mm thick aluminium.

The distance between the focus of the X-ray tube to the surface of the smartphone camera was 100 cm. The field size of the X-ray beam was $10 \times 10\ \mathrm{cm}^2$ which can cover the entire ion chamber length of 10 cm as shown in Fig. 1(c). The ion chamber which has a volume of 3.14 cc and an effective length of 10 cm (Type 30,009, PTW, UNIDOS®, Germany), was positioned alongside the smartphone to measure accurate doses and dose rates. The measured doses and dose rates of the ion chamber were used to evaluate the X-ray responses of the smartphone CMOS image sensor such as dose linearity, dose rate and X-ray energy dependence as well as angular dependence.

3. Image processing for extraction of radiation detected pixels on smartphone

The front camera in the display screen side has a matrix size of 640 × 480 (307,200 pixels), and the rear camera has a matrix size of 1920 × 1080 (2073,600 pixels) with a bit depth of 8. The video was recorded at a frame rate of 25 fps in MPEG-4 format during the X-ray irradiation. The video file was imported by MATLAB R2012a (MathWorks Inc., USA), then split into individual frames. The frames from the 0–3 s were discarded, because they usually contain some sparkle noises.

The total pixel intensity of the frame I can be calculated by the following Eq. (1).

$$I = \sum_{x=1}^{m} \sum_{y=1}^{n} f(x, y) \tag{1}$$

Where, $f(x, y)$ represents the pixel intensity of the frame at the x-and y-coordinates, m and n represent total number of rows and columns of the frame respectively.

The noise level was calculated by using Eqs. (2) and (3).

$$\text{Noise level} = \bar{I}_N + 3\sigma_N \tag{2}$$

where, $\bar{I}_N$ and σ_N represent the average and standard deviation of the total pixel intensity of the frames between the interval 3–5 s which corresponds to the frame number of 75–125.

$$\bar{I}_N = \frac{1}{50}\sum_{k=75}^{125} I_k, \quad \sigma_N = \sqrt{\frac{1}{50}\sum_{k=75}^{125}\left(I_k - \bar{I}_N\right)^2} \tag{3}$$

The value k is the frame number and I_k is the total pixel intensity of the frame at the frame number k.

The frame exceeding the noise levels of the each red, green and blue component was extracted as a radiation-interacted frame. Subsequently, the frame was converted to the grey scale and the total pixel intensity of the frame was calculated. In order to reject the noise pixel intensity from the radiation interacted frame, the average noise value $\bar{I}_n$ was subtracted from the total pixel intensity of the radiation interacted frame by the following Eq. (4).

$$\text{Radiation induced pixel intensity} = I_R - \bar{I}_N \tag{4}$$

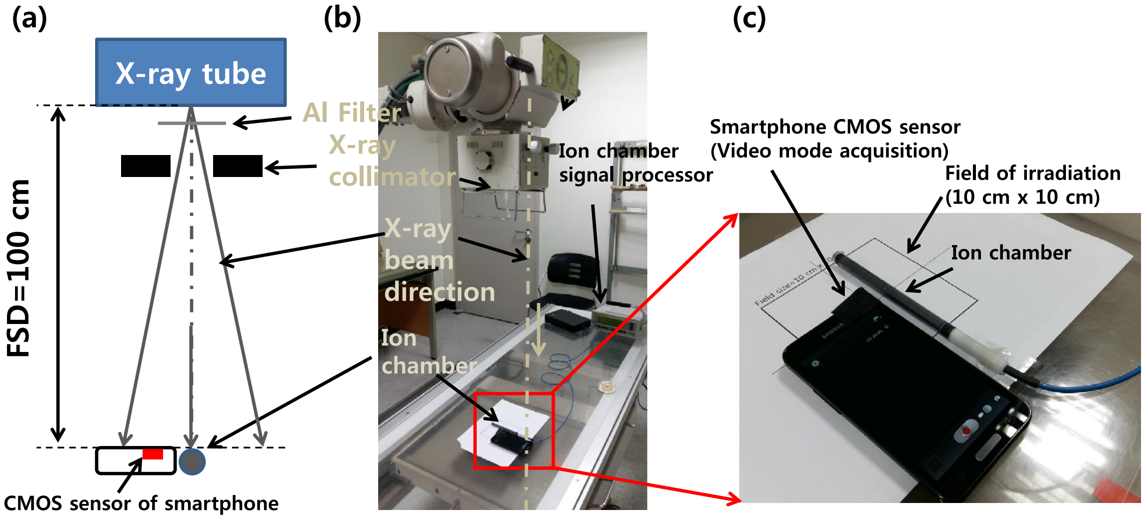

Fig. 1. Schematic diagram and photographs of the experimental setup for radiation detection with the smartphone: (a) schematic and (b) experimental setup for radiation detection with the smartphone, and (c) ion chamber with the smartphone inside the $10\ \mathrm{cm}^2$ X-ray irradiation field.