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A study of radiation measurement using CMOS camera in smartphones digital camera

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Abstract

Background: X-ray radiography has played a vital role as a part of radiation technique in non-destructive testing (NDT). This technique is utilized as a tool which is invisible by visual inspection. Combining the availability of smart phone and the high efficiency of their CMOS camera, there has been an interest in using smart phone as a radiation monitoring device. Objectives: This research aims to study a radiation counting system using a CMOS camera in smartphones with Android and IOS systems, in comparison with ionization chambers. Materials and Methods: The X-ray counting system in this study consists of an X-ray generator, smartphones with Android and IOS systems, ionization chambers and the ImageJ program for image analysis. The distance from X-ray generator to image receptor (smartphone) was set at 100 cm. The voltage of the X-ray generator was fixed at 100 kVp, while the exposure time was varied from 2, 4, 6, 8, 10, 12, 16, and 20 mAs. The radiographic images were received by a CMOS sensor of the digital camera in the smartphones, which were sealed with duct tape to avoid any unrelated visible light. The radiographic images were analyzed in terms of image intensity, radiation counting capability, and standard deviation (S.D.). Results: Experimental results showed that the exposure time (mAs) of X-ray generator affects the quality of radiographic images in terms of radiation counting value, image intensity, and noise. Image intensities of radiographic images darkened with increasing exposure time from 2 to 20 mAs. The radiation counting value and image noise increased with increasing exposure time in the range of 2 to 12 mAs. A similar phenomenon was also observed by using ionization chambers. However, the exposure time level cannot exceed 8 mAs since it is over the limit of a CMOS sensor. Conclusion: The X-ray counting system using radiographic images from a smartphone proposed in this research is an important basis for developing a radiation counting system, as well as other different techniques in the future.

Keywords: Radiation measurement, Smart phone, CMOS camera, Radiographic image

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1. Introduction

Medical devices and equipment involving radiation have been extensively utilised in clinical practices for many decades. Even though the radiation protection and shielding are fully implemented, an increased level of occupational radiation dose unavoidably affects medical staffs which could potentially be concerned for their personal health in the long run. Consequently, occupational dose exposures are carefully recorded and monitored using a personal dosimeter. Conventionally, Ionization Chamber (IC), a detector collecting all charges created by direct ionization within the gas through an electrical current, is extensively used for radiation detection and measurement [1].

Non-destructive testing (NDT) has played a vital role in the industrial sector, as well as research and development sector worldwide. NDT is a well-known and commonly used analysis technique in science and technology industry to evaluate the properties of a material or system without causing any damages, as implied by its name. Common NDT methods include radiographic testing, visual testing, ultrasonic testing, eddy current testing, liquid penetrant testing, and magnetic particle testing. Among these methods, radiographic testing is the most extensively used method due to their capability in detecting minute hidden defects and cracks inside the specimens, which are not visible by inspection. Generally, radiographic image is recorded by film, which requires a post-processing step using developing and fixing solutions. Film development is a long and complicated process. As an alternative, a digital image plate is used to generate a real-time radiographic image in digital format. The image can be readily available without requiring a post-processing step. However, the cost of a digital image plate is rather high due to their advanced technology and not easily accessible. As a result, a digital image plate is only available and utilized in well-established institutions such as hospitals and research centers.

Over decades, smart phone has become an important device that made modern life easier and more convenient in many ways. It has become ubiquitous rapidly throughout the world. There is a constant increase of technological advancement for mobile technology. One example is an advancement of digital camera that is embedded in smartphone, which serves an important function of recording pictures and videos using CMOS sensor. CMOS sensor is an electronic chip that converts photons to electrons for digital processing. Like other semiconductor technologies, CMOS chips are produced by photolithography. The chips feature an array of minute light-capturing cells that pick up the photons at their various wavelengths as focused by a lens, translating them into electrons, much like a tiny solar cell. The CMOS cells are surrounded by transistors, which amplify the charge of the electrons gathered by the cells, sending them across the chip by tiny wires in the chip's circuitry. A digital-to-analog (DAC) converter at one corner of the device reads the electrons and translates the differing charges of individual cells into pixels [2-4].

Nowadays, the performance of digital camera using CMOS sensor on smartphones has been improved in many aspects such as camera pixel depth, camera frame rate, and computing speed. These advanced features enable the possibility of using digital camera function in smartphones to record radiographic images from X-ray radiation. Combining the availability of smartphone and the high efficiency of their CMOS camera, there has been an interest in using smartphone as a radiation monitoring device [1].

In this research, the objectives aim to study a radiation counting system using a CMOS camera in smartphones with Android and IOS systems, in comparison with ionization chambers.

The efficiency and feasibility of using smartphones with CMOS image sensors were evaluated in order to use a smartphone as a radiation monitoring device for medical staffs. The characteristics of the CMOS sensors in smartphones in response to varying parameters of X-ray generator were evaluated. Radiographic images taken from smartphones of both Android and iOS operating systems were analyzed and calculated for image intensity, standard deviation (S.D.), and signal-to-noise ratio (SNR). The results were compared with radiation counts detected using an ionization chamber. The experiments conducted in this work aimed to investigate the feasibility of using radiographic images from smartphones as a radiation monitoring device for medical radiation [5-7].

2. Experimental Setup

The experimental apparatus consisted of the X-ray generator (Shimadzu Model R-20 brand), two smartphones; Samsung A50 Android Version 10 (Model SM-A505F/DS 25 MP, f/1.7, 26 mm Pixel Size 1.12 µm.), and iPhone Xs iOS (Version 13.5.1: Model A2097 12 MP, f/1.8, 26 mm, Pixel Size 1.4 µm.), and ionization chamber. The smartphone/ionization chamber was located 100 cm. away from the X-ray generator on top of a lead sheet to avoid scattering radiation. The diagram and pictures of the experimental setup are shown in figure 1.

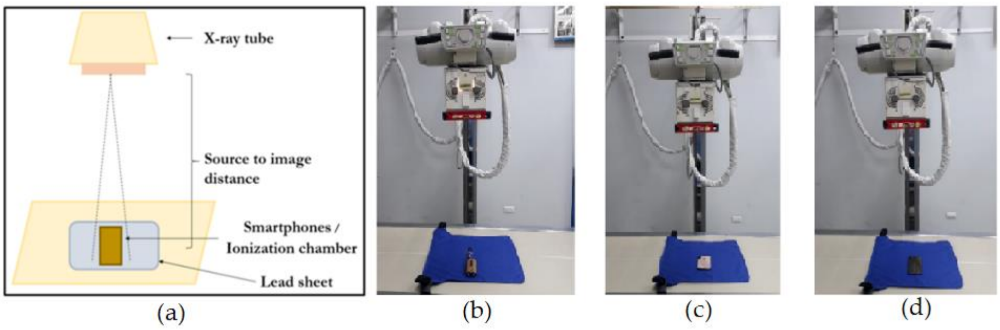


Figure 1 (a) The diagram of the experimental set-up, The set-up of ionization chamber in (b) iPhone Xs iOS Version 13.5.1 in (c) and Samsung A50 Android Version 10 in (d).

The experimental protocol to acquire a radiographic image is implemented as follows. Firstly, the smartphones were sealed with duct tape to avoid any unrelated visible light and operated in a video recording mode. The X-ray generator exposed X-ray radiation through a digital camera with CMOS sensor in smartphone with a fixed voltage at 100 kV. Electrical current and exposure time (mAs) were varied at 2, 4, 6, 8, 10, 12, 16, and 20 mAs, in order to study the differences of image intensity from varying X-ray generator settings. The longer the exposure time, the more light is allowed through the lens of the camera. Other settings of the digital camera for both Android and iOS smartphones were fixed for all the experiments. The X-ray radiation was aimed at the center of smartphone digital camera and covered the field of view (FOV) of 7 x 7 cm^2. Similar experimental procedures were conducted for both Android and iOS smartphones, as well as the ionization chamber.

For ionization chamber, the radiation count for each experiment was recorded using Digitizer utilities program. For smartphones, the radiographic images were analyzed using the ImageJ program. Firstly, the region of interest (ROI) for each image was selected. Examples of radiographic images and a snapshot of the ImageJ program are shown in figure 2. The average $(\bar{I})$ and (σ) of image pixel intensity can be calculated by the following equations:

$$\bar{I} = \frac{1}{i}\sum_{k=1}^{i} I_k \tag{1}$$

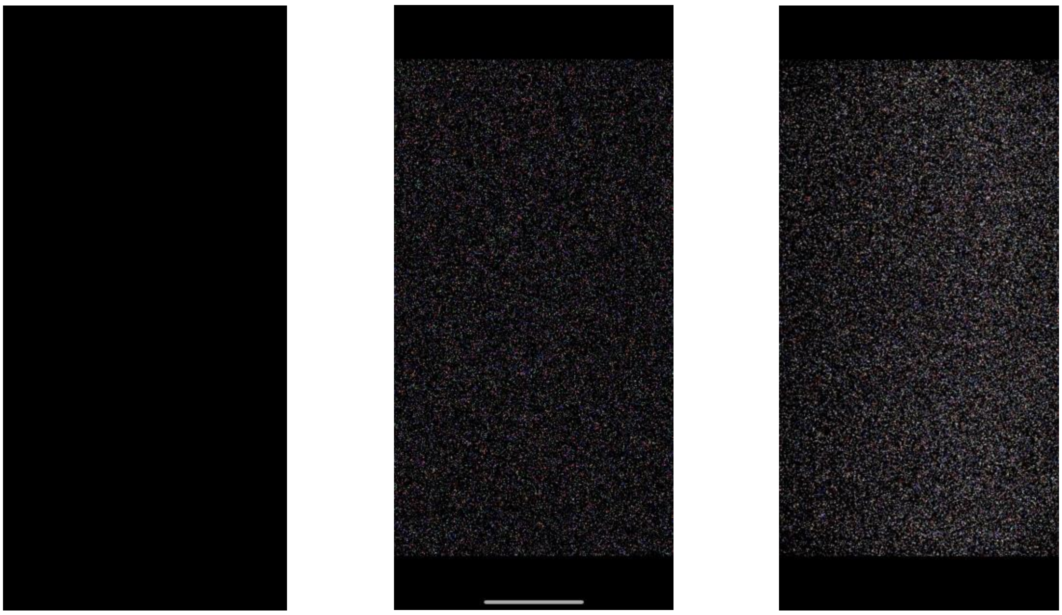
$$\sigma = \sqrt{\frac{1}{i}\sum_{k=1}^{i}(I_k - \bar{I})^2} \tag{2}$$

$$SNR = \frac{\bar{I}}{\sigma} \tag{3}$$

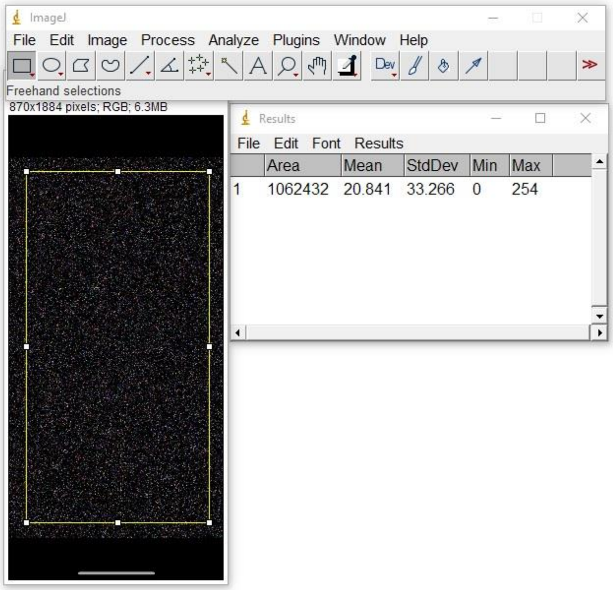
where k and i denote the pixel number and total number of pixels in the ROI, respectively. I_k is the image intensity of pixel number k.

Three quantitative metrics including an average image pixel intensity, standard deviation (S.D.) and signal-to-noise ratio (SNR) were extracted from the ROI of radiographic images using ImageJ program. These metrics were compared with the radiation counts from ionization chamber. The experiments were repeated 3 times and the average values of each metric are shown in Table 1.

Therefore, the proposed algorithm in the experiment is the distance from X-ray generator to image receptor (smartphone) was set at 100 cm., the voltage of the X-ray generator was fixed at 100 kVp and the exposure time was varied from 2, 4, 6, 8, 10, 12, 16, and 20 mAs. And then, the radiographic images were analyzed in terms of image intensity, standard deviation (S.D.) and signal-to-noise ratio (SNR).



(a) (b) (c)



(d)

Figure 2 (a) Radiographic images with no radiation exposure, 100 kV and 10 mAs X-ray taken with (b) iOS smart phone and (c) Android smart phone. (d) A snapshot of ImageJ program with selected ROI.

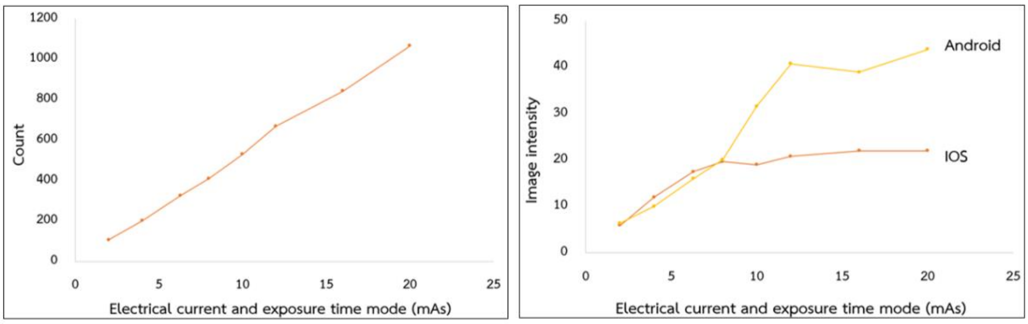
Table 1 Radiation counts from ionization chamber, mean of image intensity, standard deviation, and signal-to-noise ratio from smartphones of iOS and Android, in terms of varying electrical current and exposure time (mAs)

mAs	Counts	Mean of Image Intensity		standard deviation (S.D.)		signal-to-noise ratio (SNR)	
	IC	iOS	Android	iOS	Android	iOS	Android
2	107.3	5.9	6.4	16.5	15.1	0.358	0.424
4	202.3	12.0	10.0	24.8	19.5	0.484	0.513
6	326.1	17.5	16.0	30.4	25.6	0.576	0.625
8	410.9	19.7	20.1	32.5	29.0	0.606	0.693
10	530.7	19.0	31.6	31.7	37.7	0.599	0.838
12	669.1	20.8	40.8	33.3	41.7	0.623	0.978
16	842.9	22.0	39.0	34.8	39.2	0.632	0.955
20	1066.7	22.0	43.9	34.7	42.8	0.634	1.026

3. Results and discussions

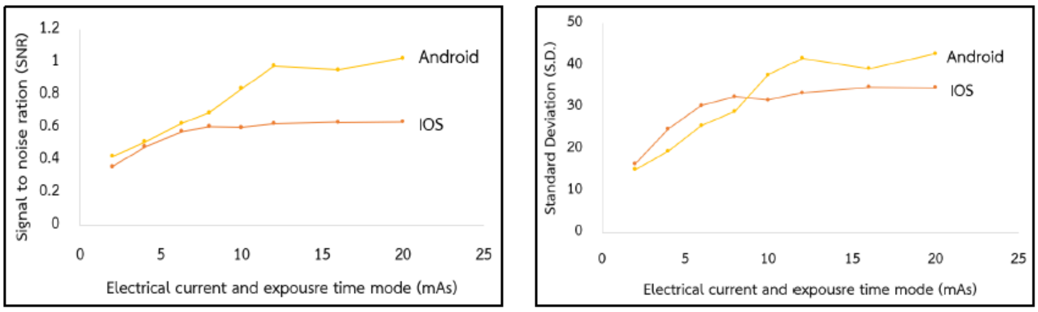
The plots of radiation counts from ionization chamber, image intensity, standard deviation, and signal-to-noise ratio from smart phones of iOS and Android, in terms of varying electrical current and exposure time (mAs) as presented in Table 1 are shown in Figures 3 and 4. The first observation that can be made from Figure 3 is that radiation counts from ionization chamber and image intensities from smartphone images increase with an increasing exposure time from 2 to 20 mAs. This relation means that the radiographic images from smartphones responded in the same way as ionization chamber. However, the radiation counts as recorded by ionization chamber increased in a linear pattern from the lowest to the highest mAs, whereas the image intensity from iOS and Android smartphones did not follow the same pattern. In Figure 3 (b), the intensity of image taken from both smartphones linearly increased from 2 to approximately 8 mAs. From 8 mAs onward, the image from iOS smartphone demonstrated a steady and flat increase up to 20 mAs with a slight drop at 10 mAs. The intensity of image from Android smartphone was still sharply increased from 8 to approximately 12 mAs before a slight drop and increase at 15 and 20 mAs, respectively. The phenomena mentioned above can be concluded that the smartphone of Android operating system can respond to X-ray radiation better than iOS smartphone, especially when the exposure time is greater than 8 mAs. However, the limit of iOS smartphone was found at approximately 12 mAs when the image intensity did not respond very well according to the increase of exposure time. The reason was due to the limitation of CMOS sensor in the smartphone digital camera.

In addition to the comparison between responses of image intensities from smartphones and radiation counts from IC, the S.D. and SNR of images from iOS and Android smartphones are compared as a function of increasing exposure time as shown in Figure 4.



(a) (b)

Figure 3 (a) Radiation count from ionization chamber, (b) Intensity of radiographic images from iOS and Android smart phones as a function of varying electrical current and exposure time mode (mAs).



(a) (b)

Figure 4 (a) signal-to-noise ratio (SNR) and (b) standard deviation (SD.) of radiographic images from varying electrical current and exposure time mode (mAs) with iOS and Android smart phones.

According to Figure 4, the SNR of radiographic images from Android smartphone increased in a greater proportion than iOS smartphone, as the electrical current and exposure time increased from 2 to 20 mAs. This demonstrated that the radiographic image taken from

Android smartphone contained more informative signal than that of the iOS smartphone since SNR is an indicator of image quality. However, the plot of S.D. in Figure 4 (b) showed that the deviation of information on the radiographic images taken with Android was stronger than that of iOS smart phones. Analysis of the trend of the SNR with mAs graph found that the response of the IOS system in the range of mAs = 2-8 increased in the logarithm curve and mAS = 10-20, the response is stable. The response of the IOS system in the range of mAs = 2-8 increased in the straight line and SNR values drop at mAs = 20. The mAs adjustment for each smartphone should be adjusted within the recommended range.

This means that even though the SNR of Android image is greater, the proportion of noise presented in the images from Android smart phone is also larger.

4. Conclusion

The experiments conducted in this work has proven the possibility of using smartphones as radiation monitoring device. The radiographic images were captured by CMOS sensors embedded in digital cameras of smartphones, which have a structure of semiconductor in the same way as the radiation monitoring instrument.

Conventionally, the term “ionization chamber” refers exclusively to Ionization chamber dosimetry is the most common method used for absorbed dose measurements in radiation beams of X-ray generators. They are precise, reproducible, the oldest radiation detector used, can be small and can easily be related to the national standards. However, ionization chambers require certain precautions and corrections before the readings can be interpreted in terms of a dosimetry quantity. Corrections should be applied for atmospheric conditions, electronic characteristics, chamber design, such as measuring the radiation sensitive volume, and material being air [8]. Noted: The radiation counting value increased with increasing exposure time and voltage value. From the experimental results, it can be concluded that the factors involved in radiographic image quality consist of radiation count, image intensity, signal-to-noise ratio (SNR) and standard deviation (S.D.). The increased electrical current and exposure time (mAs) results in an increased number of X-ray impinging on radiation detection device. The comparison between the radiation counts detected by ionization chamber (IC) and image intensity from smartphones demonstrated a capability of smartphones in detecting X-ray radiation, with Android smartphone being better than iOS at responding to the radiation at mAs ≥ 8. However, the limitation of Android smartphone was found at mAs ≈ 12.

The other two metrics including SNR and S.D. were also investigated for radiographic image quality and found that the SNR extracted from radiographic images of Android smartphone are higher than that of iOS smartphone. However, the S.D. of Android smartphone image were also found to be higher, which means that the proportion of noise level in the image was also high.

When the X-ray tube current is greater, it will make the X-ray quantity more valuable. It makes the CMOS convert to more image brightness. Noted: intensity and signal of radiographic image are greater. Therefore, the difference between background and signal is greater resulting is higher noise values. Finally, when calculating SNR. This increases the SNR value according to the mAs value.

In order to produce a quality radiographic image for radiation monitoring, it is important to adjust the balance between all settings of the X-ray generator and digital camera such as the range of mAs and types of smartphones (iOS and Android systems). The experiments in this research were studied to understand the relationship between all factors and image quality metrics in terms of radiation count value, image intensity, signal-to-noise ratio (SNR) and standard deviation (S.D.). The X-ray radiographic imaging system, using iOS and Android digital cameras proposed in this research, can be used as a starting point to replace expensive devices, i.e., a digital plate or a digital detector. The X-ray radiation imaging system proposed in this research can be found from an inexpensive and easily accessible device which is an important basis for development of a different technique in the future.

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