

# Radiation exposure factors optimization of X-ray digital radiography for watermarked art pottery inspection

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## Radiation exposure factors optimization of X-ray digital radiography for watermarked art pottery inspection

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**Abstract:** Non-Destructive Testing (NDT) is a technique for detecting a defect in an object without causing damage. NDT technology can be utilized in the arts for inspection purposes. The NDT technique that can be used for the inspection of art pottery is digital X-ray radiography. It can inspect until the contents inside the art pottery without causing damage. To obtain a high quality of watermarked art pottery image using digital radiography, the radiation exposure factors should be optimized. In this work, optimization was done by varying the voltage, current, and exposure distance. Then, the radiography images were analysed using Contrast to Noise Ratio (CNR). From the analysis, it can be determined that the optimum exposure factors are 60 kV of voltage, 16 mA of current, and 100 cm of exposure distance.

### 1. Introduction

Non-Destructive Test Technology has been widely used in the arts, especially in craft arts. The Boston Museum of Fine Arts has used the NDT for inspection so that it can be known how and when to make an artwork. It can even determine the origin of the artwork (whether authentic or fake) and pre-conservation diagnostics [1].

The use of NDT for craft artwork inspection is still rare in Indonesia. In fact, utilizing NDT can increase the value of craft artwork by giving an authenticity mark (Watermarking) and can only be seen with the NDT technique, so that its authenticity can be guaranteed. Watermarking can be one of the solutions useful for copyright protector because it can be used as a marker of a product so that its authenticity is maintained. The craftsmen can make symbols on certain pottery or even every series of pottery types that will be made [2]. Watermarking is the most popular data hiding technique because it has three advantages, including not being seen directly, inseparable from the data or objects that are given a watermark, and can be adjusted to the type of data and treatment at the time of watermarking. These advantages make the watermarking method superior to other methods [3].

The NDT technique that can be used for the inspection of art pottery is digital X-ray radiography because it can inspect until the contents inside the art pottery are known without damaging the art pottery [4]. Digital X-ray radiography is one of the NDT techniques that can be used as a tool to describe the internal parts of an invisible material without damaging and splitting the material [5]. Since the discovery of X-rays by Wilhelm C. X-ray in 1895, radiographic techniques have been used in various fields including industrial fields such as welding pipe joints, medicine, and archeology [6-8]. This technique uses the changes in the intensity of X-rays transmitted through detected samples [9].



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The use of digital X-ray radiography systems for NDT purposes has the advantage that the radiation energy can be adjusted to the type and thickness of the sample. In addition, radiographic images can be recorded, stored and processed digitally using a computer. However, to get high-quality watermark art pottery images, it is important to conduct research on the optimization of radiation exposure factors. Optimization of radiation exposure factors is done by assessing image quality resulting from various values of exposure factors. Contrast to noise ratio method (CNR) is used to analyze image quality because it gives an objective method to examine the balance of exposure factors [10]. Previous studies which used CNR were determining exposure factors in pearl NDT [11] and testing the quality of pet radiographic images [12].

Exposure factor is a factor that determines the quality of radiographic images. This study optimizes 3 exposure factors, namely voltage, current, and exposure distance. In radiology, image quality determines the effectiveness of the diagnosis to be performed [13].

## 2. Methods

Art pottery was used in research made from clay and formed a bowl with a diameter of 20 cm and the middle base thickness of 7 mm. The type of watermark was thin wood or plywood. The plywood was cut according to the watermark design with a thickness of 2 mm using a laser cutting tool. Watermark was inserted into the pottery art right in the middle of the base. Art pottery which was exposed by X-ray was in the condition before and after being burned. Art pottery and watermarks are shown in Figure 1.

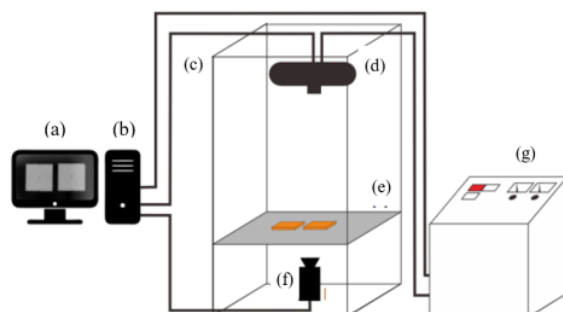


Figure 1 (a) Art pottery, (b) plywood watermark

The instrument used in the study was X-ray radiography developed by the Department of Physics, Universitas Negeri Semarang. The components of the radiographic system are X-ray tube to produce X-rays, control panel to regulate the radiation exposure factors, fluorescent screens that to convert X-rays into visible light, and Digital Single Lens Reflex (DSLR) camera sensor as a light sensor integrated with a computer so that images can be directly displayed on the monitor screen. Diagram of X-ray digital radiography is shown in Figure 2.

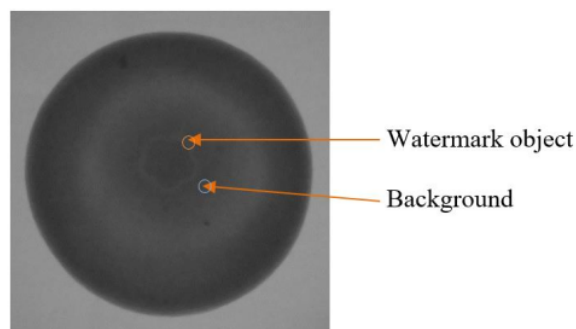
Inspection of watermarked pottery was carried out in three stages of exposure factors which are voltage optimization, current optimization and distance exposure optimization. Voltage values vary from 50 kV to 75 kV with increment of 5kV. Other exposure factors were maintained at 16 mA for currents, 0.16 for time, and 100 cm for exposure distances. The images obtained were then analysed using the CNR method. CNR is a quantitative parameter that provides information of image performance (contrast) and data quality i.e. noise caused by radiography system [14]. It is defined as the difference between the mean of region of interest (ROI) of the object ( $S_o$ ) with the mean of the ROI of the background ( $S_b$ ) divide by the deviation standard of the background  $\sigma_b$  [15]. The mathematics expression is shown in equation (1).

$$CNR = \frac{S_O - S_B}{\sigma_B} \quad (1)$$



**Figure 2** Diagram of X-ray digital radiography (a) Monitor screen, (b) CPU, (c) Copper shielding box, (d) X-ray tube, (e) Fluorescent screen, (f) Camera, and (g) Panel control

Voltage tube value which result the highest CNR was optimum voltage. Then the objects were captured by varying the current while the exposure distance was maintained at 100 cm. The current values were 16 mA, 32 mA, and 63 mA. The optimum voltage and current value was then used to optimize the exposure distance. The exposure distance was varied from 80 cm to 100 cm with increment of 5 cm. CNR analysis was done by selecting the watermark image as object and the area near the watermark as background as shown in Figure 3.



**Figure 3.** Object and background selection for the CNR analysis

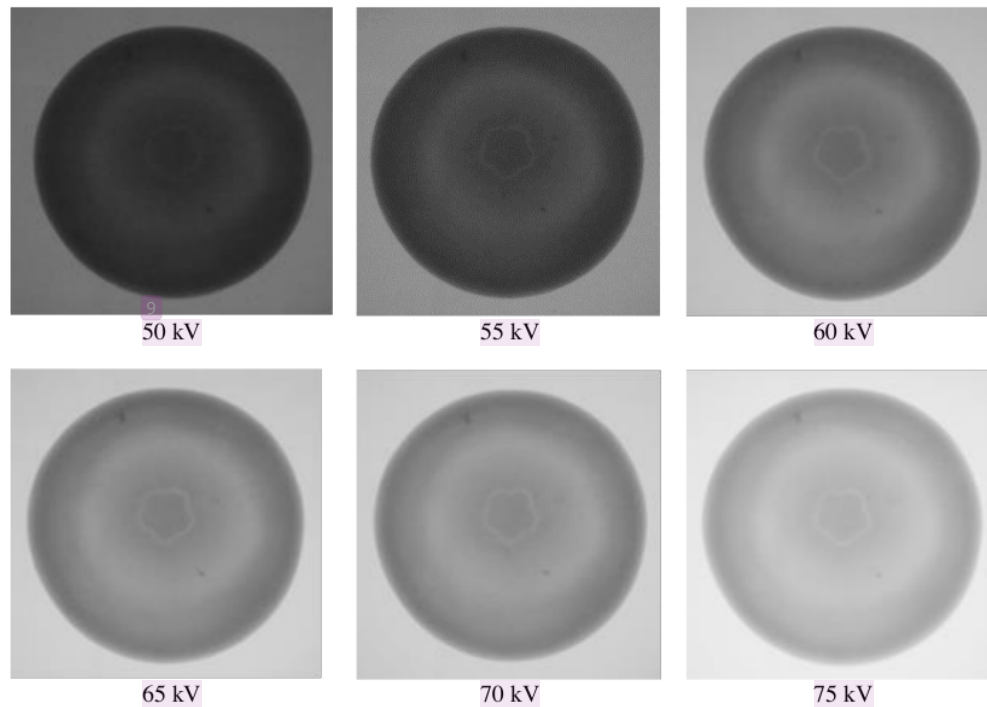
### 3. Result and Discussion

#### 3.1. Voltage Optimization

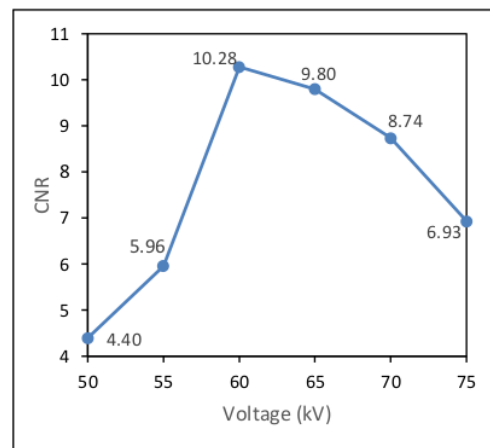
Figure 4 are radiographic images of the inspection results of watermarked art pottery for voltage tube variations of 50 kV to 75 kV. It can be observed that the higher the voltage produces the brighter the image, because the exposure X-ray energy is higher, so that X-ray has higher penetrability.

At low voltage, the image has low contrast so that the CNR value is also low. The CNR value increases when the voltage increases from 55 kV to 60 kV. A further increase in voltage makes CNR decreases. At very high voltage, X-ray energy increases and the image goes brighter, so the image

contrast decreases again and the CNR value also decreases [11]. Figure 5 shows the optimum voltage of 60 kV which produces a CNR of 10.28.



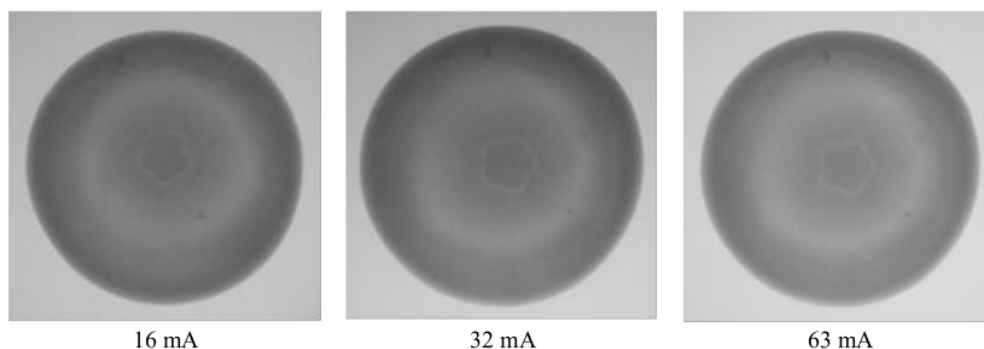
**Figure 4.** Radiographic images for various voltages



**Figure 5.** CNR vs. voltage for watermarked art pottery image.

### 3.2. Current Optimization

The effect of current on the CNR value is tabulated in Table 1. High current causes the intensity of X-ray radiation that penetrates the object to be higher. It causes the image to be brighter and CNR to decrease. It was showed that the optimum current is 16 mA with CNR of 10.28. If seen visually in Figure 6, the effect of the current on the image contrast is not significant.



**Figure 6.** Radiographic images for various currents

**Table 1.** CNR for various current values

Current (mA)	ROI mean of the object	ROI mean of the background	CNR
16 mA	113	102	10.28
32 mA	115	105	9.62
63 mA	137	128	8.82

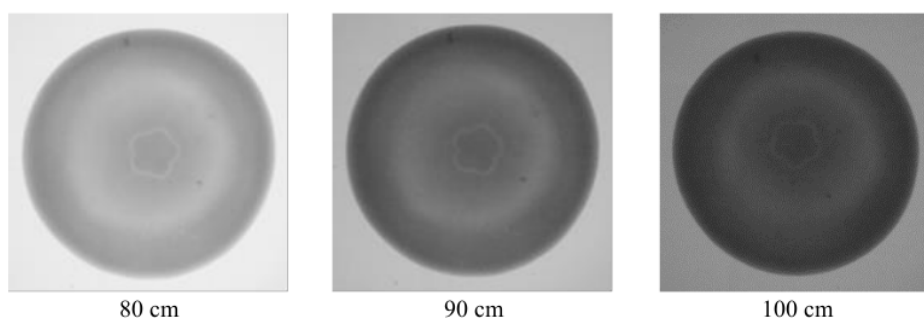
### 3.3. Exposure Distance Optimization

The exposure distance affects the intensity of the radiation reaching the object. By shortening the exposure distance, the amount of radiation that hits the object will increase because scattering radiation decreases. Therefore, the shorter the exposure distance causes the image to be brighter and the contrast to decrease. The effect of the exposure distance on the CNR values are tabulated in Table 2.

**Table 2.** CNR for various exposure distance

exposure distance (cm)	ROI mean of the object	ROI mean of the background	CNR
100	113	102	10.28
90	120	110	9.52
80	170	162	7.48

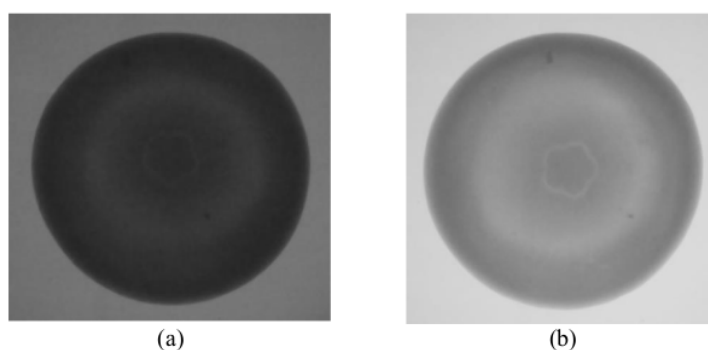




**Figure 7.** Radiographic images for various exposure distance

For an exposure distance of 100 cm, the watermark is most clearly seen visually (see Figure 7) and the CNR value obtained is also the highest.

From CNR analysis, it was found that the highest CNR is 10.28 and the lowest CNR is 4.40. The images resulting both CNR values are shown in Figure 8.



**Figure 8.** (a) The image with CNR of 4.40 and (b) the image with CNR of 10.28

#### 4. Conclusion

Optimum exposure factors of X-ray digital radiography for watermarked art pottery inspection are 60 kV of voltage, 16 mA of current, and 100 cm of exposure distance. The CNR value obtained from the image with those exposure factors is 10.28.

#### Acknowledgment

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