Design of an X-ray plane prototype with Android-based absorption dose estimation calculation

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Abstract: The development of an android-based radiation dose estimation system for X-ray plane, which incorporates tube voltage and tube current settings, is anticipated to reduce costs and minimize radiation doses. This prototype employs an X-ray tube with a single tank low-frequency specification and a tube current capability at high tension transform (HTT) of 10 mA, an exposition time of 0.1 s, and variations in tube voltage generated by 45 kV, 50 kV, and 60 kV. The prototyping phase encompasses the design of the hardware components, including the x-ray tube generator, voltage divider circuit, power supply, and Arduino Nano, which serves as the data processing unit. The software design employs the Skript programming language for deployment on Android and ESP32 devices. This involves the initial installation of the Blink application on Android via the Play Store. The prototype underwent a series of tests, including hardware testing, reproducibility testing, and peak voltage testing. Irradiation time testing and dose in microGray with the amount of CV passing at 0.05 (0.016) were also conducted. Additionally, software testing was performed to assess the accuracy, reproducibility, linearity, and dose estimation capabilities of the tube voltage settings.

Keyword: radiation dose, x-ray tube, dose testing, tube current, x-ray system

1. Introduction

X-ray equipment is a type of radiological equipment utilized in the medical field for diagnostic and screening purposes, employing the use of X-rays. Conventional X-ray equipment currently employs a control system to limit the dose output exposed to the patient. The dose setting through the exposure factor utilizes a manual method to control the tube voltage (kV), tube current (mA), and exposure time (s), which are displayed in milliampere second (mAs) multiplication unit values that can reach 600 mAs. (Fisika, Pendidikan, Dan, Pengetahuan, & Bandung, 1996). The WHO Manual of Diagnostic Imaging Radiographic Technique and Projections recommends radiographic examinations with mAs values between 40 and 50. However, the safety standard for the use of x-ray devices for health purposes should range from 1 to 15 mAs. If the exposure time to the patient is excessive, the x-ray device may produce an excess of radiation that is potentially harmful (Sandstrom, 2011; Walker, Voutchkov, McKenzie, & Barned, 2016).

Nuclear Power Supervisory Agency (BAPETEN) has established regulations pertaining to the permissible dose limit of X-ray radiation. In accordance with Regulation Number 4 of 2013, issued by the Head of BAPETEN, concerning Radiation Protection and Safety in the Utilization of Nuclear Power, the permitted radiation dose limit for a radiation worker is 20 mSv per year, calculated as an average over a period of five consecutive years. In any given year, the effective radiation dose shall not exceed 50 mSv (Roo'in Mas'uul, Putro, Marlina, Budiyono, & Handoyo, 2024; Şahmaran & Çoraplı, 2024). In exceptional circumstances, the effective radiation dose may reach 5 mSv in a single year, provided that the average dose over five years does not exceed 1 mSv per year. These provisions are designed to protect radiation workers and the general public from excessive radiation exposure that may cause adverse health effects. (Badan dkk., 2020). In accordance with BAPETEN Regulation No. 4 of 2020, pertaining to the safety of radiation in the utilisation of X-ray aircraft for diagnostic and interventional radiology purposes, Article 38 stipulates that the radiation leakage of X-ray aircraft does not exceed 1 mGy (one milligray) in 1 (one) hour at a distance of 1 (one) meter from the focus (BAPETEN, 2020).

The latest generation of X-ray equipment uses AEC (Automatic Exposure Control) but does not yet have an adjustable dose display on the control panel (Boissonnat dkk., 2023; Saito dkk., 2022; Suyatno, Yuniarsari, Syawaludin, & Puspiptek, 2010), so that the estimated dose presented is not visible directly on the monitor or LCD. Previous research made a system for controlling voltage, current and timer parameters on a *mobile X-ray aircraft type ix 7-02* using a personal computer and using an AT89S51 microcontroller. The tube voltage (kV) is set using a stepper motor that is controlled by a dimmer. The exposure time value is between 0.1 and 1 second. The conventional control system is replaced with a digital display. However, this tool has a limitation in that the exposure factor setting is still based on the habits of radiation workers, which results in the loading to the X-ray generator being biased and overloaded (Miftahul Ilmi, 2023; Mingxin, Zhijun, Wenhao, & Suiyuan, 2016).

A recent study has investigated the use of an automatic exposure control system on an Android-based X-ray generator utilising the Ecorad app, which is a derivative of the Siemens Point System. The system employs a formula to calculate the irradiation factor, with the dose received by the receptor ranging from 0.5 mR to 1.5 mR. This study addresses the Ecorad exposure factor control on an X-ray plane with a single tube voltage (kV) method. The generator utilized is a single tank low frequency generator. This study successfully calculated kV, mA, and seconds with an accurate method that has been in use since 1957 (Sukwono, 2021; Sun dkk., 2022).

It is anticipated that the resulting kV and mAs factor settings will result in a reduction in electricity consumption and a lowering of the radiation dose. This will be achieved by utilising X-ray tubes with single tank low frequency capacity and an HTT (high tension transformer) tube current of 10 mA, an exposure time of 0.1 seconds, and tube voltage variations of 45 kV, 50 kV, and 60 kV. This selection is based on observations of various high-voltage transformers, including the electron beam machine (MBE) for latex processing at PT APB (300 kV, 20 mA), industrial X-ray equipment manufactured by Philips (60 kV, 90 mA), and medical X-rays at STTN. The apparatus was manufactured in China and is capable of operating at 100 kV and 50 mA. Additionally, the design incorporates a high-voltage transformer intended for use in electron accelerator power supplies for radiographic X-ray tubes. These tubes have specifications of 220V/250 kV, 8.5 KVA, 1 phase, and 50 Hz (Susila, Santoso, Sukandar, & Santoso, 2014). This transformer selection process is done manually so that it is possible that there is a lack of accuracy in the selection.

2. Method

2.1. *Tools and Materials*

The tools and materials used in this research are laptop, Arduino nano, ESP32, DC Power Supply, single tank generator, Arduino IDE, KV Meter, Cooling fluid (Oil transformer), x-ray insert, and IoT platform which is used as a display and control system.

2.2. X-ray Generator Design

The design of the X-ray generator is done by utilizing a High Tension Transformer (HTT) or tube voltage transformer that has a current of 10 mA, a low frequency rectifier, insert tube, and transformer oil, as shown in Figure 1. All these components are wrapped using acrylic, then coated with lead (Pb) to protect from radiation.

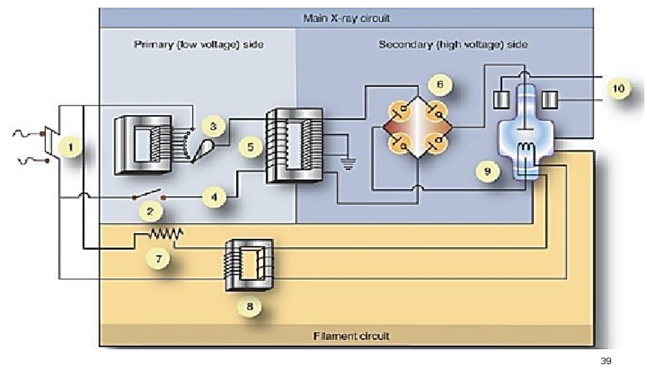


Figure 1. Generator Model System

In this study, the X-ray plane is designed to produce a generator output voltage based on the calculation of the number of turns in the primary and secondary coils with a ratio of 1:333. With this winding ratio, the output voltage from the transformer will be comparable to the output voltage on the X-ray tube, thus supporting the desired X-ray generation process.

2.3. System Model Controller

This prototype X-ray car aims to test the quality of the X-ray tube and measure the dose and characteristics of the device made, by utilizing a single tank X-ray generator with a low frequency (50 Hz) and a capacity of 10 mA, and a tube voltage that reaches 60 kV. This prototype will provide a clear picture of the optimal utilization of X-rays. In addition, this prototype can be used for tube voltage (kV) reproduction tests and dose tests in milligrey (mGy) and microGrey (µGy) units. The prototyping of this device requires the design of the model system shown in Figure 2 below,

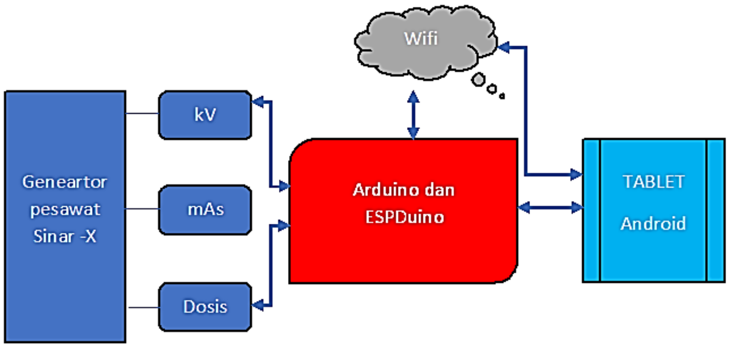


Figure 2. X-ray Aircraft Prototype Control Model

The controls include tube voltage control, where this amount is set when the X-ray output shows the measurement results. The results of this measurement are entered into the Android system. The initial tube voltage (kV) is entered and changes are made using the tablet. The tube current control is the next display, which is mAs or milliamperesecond, a quantity used for exposure that affects the dose and the level of blackness of the radiographic results.

2.4. Software Design

The software design begins by determining the variables that affect X-rays, such as the grid (G), which is ignored because this study does not use a grid. Other variables include exposure current (mA), which is taken from the HTT capacity value of 10 mA, time (Time), and exposure distance (d) by determining the peak voltage (kVp) of the designed device. Once these variables have been obtained, mathematical calculations are performed using a wireless connection to determine the choice of tube voltage (kV) and exposure current (mAs) so that the dose estimate can be displayed. The software system to be used is further described in Figure 3.

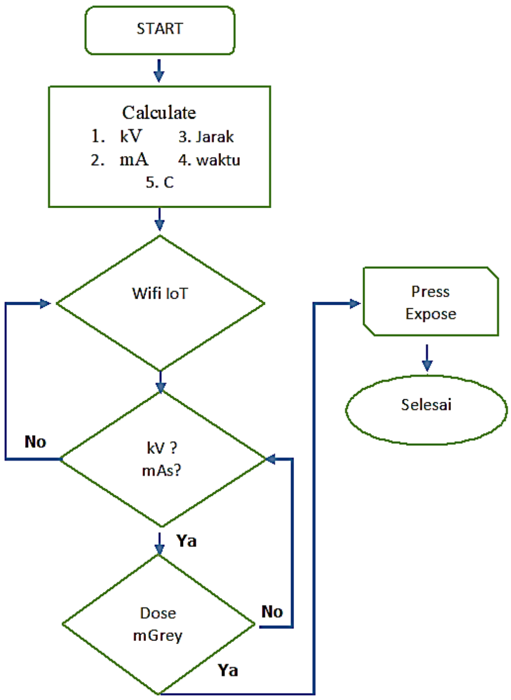


Figure 3. Software System Design

3. Results and Discussion

3.1. X-ray Tube Generator Testing Results

The test results of the X-ray generator are focused on calculating how consistent the input value from PLN or power supply to the filament transformer and to the HTT (High Tension Transformer) so that it is produced as shown in Table 1.

Table 1. X-ray Tube Generator Output

No	Voltage Input to HTT	Input Voltage To Filame Transformer	Voltage Output From X-ray Tube	Results
1	150 Volt AC		45 kV	Read
2	160 Volt AC	175 Volt AC	50 kV	Read
3	180 Volt AC		60 kv	Read

In the test results of this generator tube obtained from the output measurements that have been designed the number of windings on the previous *step up* transformer is 333 times more secondary windings than primary windings with a primary wire diameter of 0.7 mm and secondary 0.02 mm.

3.2. Software Testing Results

3.2.1. Control System and Wifi Testing

The program utilized in this design is the Blink IoT application. The preliminary outcomes of the program can be observed in Figure 4. Previously, this program was made available for download at no cost via the Google Play store. Following the installation of the application, the software will prompt the user to activate the Wi-Fi communication system, ensuring the optimal functioning of the connectivity process.

Figure 4. X-ray Control View on Blynk App

3.2.2. Exposure Program Testing

Testing this program is done by activating the Blink application after it is installed and ensuring that the Wi-Fi connection is connected. After that, the user can adjust the menu options on the application display by shifting the kV and mAs values. These changes will automatically update the dose value displayed on the Android screen directly. The program interface can be seen in Figure 5.

Figure 5. Exposure Program Menu Display

3.3. Suitability and Irradiance Time Results

3.3.1. Tube Voltage Accuray

Testing at tube voltage accuracy is carried out to obtain the appropriate voltage. In this test, BAPETEN regulations set the amount of deviation by 10%. The following are the test results with the mAs parameter of 10 mAs. The test results can be seen in Table 2.

Table 2 X-ray Tube Output Voltage

No	kVp-set	kVp value	error (%)	Test pass value	uGy	uGy/mAs
1	50	48,90	2,2%	e max ≤ 10%	50,06	5,01
2	50	48,2	3,6%		57,73	5,77
3	50	48,5	3,0%		54,09	5,41
4	60	59	1,7%		58,98	5,90
5	60	61,9	3,2%		62,83	6,28
6	60	57,2	-4,7%		64,56	6,46

3.3.2. Linearity Dosage Results

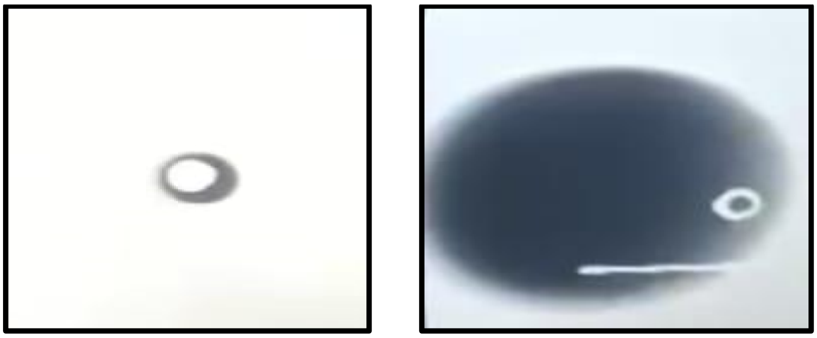
In order to ascertain the dose produced by varying milliampere (mA), linearity testing is required. It can be expected that as the thickness of the object increases, the dose will also increase, thus ensuring a stable image. The test results can be seen in Table 3.

Table 3 Dose Linearity Results

No	Tube Current (mAs)	Dose (µG)	uGy/mAs	CL	Test pass value
1	8,24	633,1	76,83252	0,3245138	CL ≤ 0,1
2	8,18	1018	124,4499		
3	8,39	1264	150,6555		

3.3.3. Image Testing Results

In the image test results, the lead material was used in conjunction with a pB plate, which had a diameter of 1.5 cm, attached to a CR Brand Fujifilm plate. The tube voltage was set at 50 kV, the current was 10 mA, and the exposure time was 0.1 seconds. The film distance was set at 5 cm, and 100 cm, as illustrated in Figure 6.



(a) (b)

Figure 6. System Imaging Results (a) with 5 cm distance, (b) with 100 cm distance

4. Conclusion

The developed X-ray aircraft prototype successfully functions well, as demonstrated through optimal hardware and software testing. The accuracy test results show that the prototype has a voltage (kV) accuracy rate of less than 10%, as well as linearity and reproducibility below 0.01. However, a dose linearity exceeding 0.1 indicates a discrepancy in the dose measurement results. Overall, this prototype offers a simple design with the support of Android system and Arduino module, which is able to simplify the control of complex X-ray generators to be more efficient and compact.

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