Wireless X-ray Machine Control Based on Arduino with Kv Parameters

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Abstract. High voltage (kV) on an X-ray machine is the voltage produced by the High Tension Transformer (HTT) which will give a potential difference to the X-ray machine's tube. Regional General Hospitals (RSUD) in Indonesia still widely use X-ray machines with analog systems as kV selection. This will result in the radiographer being exposed to radiation continuously when running the X-ray machine because they have to operate the tool directly. The many uses of cables on analog systems are still less efficient, therefore a wireless X-ray machine controller is designed that can reduce radiation exposure to radiographers, and reduce the use of cables on X-ray machines. This study uses Personal Computer (PC) as a place to set parameter values, namely kV. Serial communication using Bluetooth HC-05, minimum system uses ATmega 328p IC and data processing on PC using Delphi application. Measurements on the device use a multimeter to determine the input voltage for HTT. The measurement results of the parameters 60 kV, 65 kV, 70 kV, 75 kV, and 80 kV obtained the smallest correction value is 0.15 kV on the 75 kV parameter and the largest is 1.66 kV on the 65 kV parameter. The correction value is still within the tolerance value range of ±1 kV. In the measurement of distance the farthest results obtained by 6 meters with a barrier wall thickness of 9.5 cm.

1. Introduction
X-ray machine or X-ray machine is a medical device that works using X-ray machine radiation for both fluoroscopy and radiography. This beam radiates from the tube directed at the body part and will be captured by the film, so that images will form from the body parts that are irradiated. X-rays are produced in a vacuum glass tube and generally consist of sources for producing electrons, energy sources for accelerating electrons, free electron crossing, electron beam focusing, and materials for stopping electrons [1].

X-ray generators in the form of vacuum tubes containing filaments as cathodes and anodes. If heating the filament will cause electrons to come out and if the cathode and anode are given a high potential difference, the electrons will move quickly toward the anode. With the fast movement of these electrons, there will be a collision between the electrons and the anode, resulting in X-ray radiation [2].

The use of X-rays in the field of nuclear medicine is one way to improve public health. This application has quite a variety ranging from radiation for diagnostics, dental X-ray examination and the use of X-ray radiation for therapy. The diagnostic tool commonly used in regional public hospitals (RSUD) is an X-ray machine (photo x-ray) for photos of the thorax, bones of the hands, feet and other organs of the body [2].
X-ray machine has several parts, namely control system, high voltage and X-ray tube. When the X-ray machine is about to run, it is necessary to set several parameters, namely high voltage (kV), current (mA) and exposure time. These three parameters must have high accuracy, so that the X-rays obtained can meet medical standards. The conventional X-ray machine control system uses many analog systems, the operation is done manually so that it can result in the speed of data values obtained that are less accurate which will affect the X-rays produced [1]. The most dangerous thing for radiographers and patients is excessive radiation. Radiation affecting the human body can cause harm to workers from the lightest to the most fatal. The degree of this effect depends on several factors, namely the type of radiation, the length of radiation, the distance of the source to the body and the presence or absence of a barrier (shielding) between the radiation source and the worker [3]. Excessive dose of X-ray radiation can cause the process of ionization in soft tissues, organs and fluids in the human body resulting in cell damage that can trigger cancer cells [4].

Research conducted by Ferry Suyatno in 2010 which aims to engineer a digital system and microcontroller to improve the selection of parameters on the X-ray machine to get accurate results. The selection of voltage using a stepper motor that is controlled by a microcontroller, so that the selection can be made automatically, as well as for the parameters of the current and the timer exposure is controlled by a microcontroller, so that the magnitude value is accurate [1]. The advantage of this tool is that the data obtained is more accurate than previous conventional X-ray machine systems. Sujatno's research in 2013 which aims to create a control system on a microcontroller-based X-ray machine with a personal computer interface using BASCOM 8051 software and a program with Visual Basic 6.0 software to regulate voltage, current and time values to get a more accurate data value compared to Previous X-ray machines [5]. Engineering of the control system using the AT89S51 microcontroller and setting parameter values via personal computer. The advantage of this tool is using the selection of kV, mA, and time using a PC processed by a microcontroller so that the data obtained is more accurate. Referring to the background and research references above, the "Arduino-based Wireless X-ray Machine Control System" was created by creating an arduino-based digital system to obtain output values with high accuracy and adding wireless technology to conserve cable usage.

1.1 X-ray machine
X-rays or X-rays are electromagnetic waves with very short wavelengths (1 Å = 10-8 cm), so they have high penetrability. There are 2 types of events in the process of producing X-rays, namely Bremsstrahlung X-rays and Characteristic X-rays. X-rays are produced by shooting metal targets with fast electrons in a vacuum cathode ray tube. When electrons hit a metal target, X-rays will emit from the surface of the metal, known as Bremsstrahlung X-rays. X-rays can also occur through the process of moving electron atoms from higher levels to lower energy levels. Because each type of atom has a different electron energy level, the X-rays that are formed are called characteristic X-rays with discrete energy spectrum [6]. The brightness of the resulting x-ray image is estimated from the size of the x-ray source [7]. The X-ray machine is one of the imaging devices used as a diagnostic tool [8]. Basically an X-ray machine consists of the main parts, namely the X-ray tube, a high voltage source (HV), and the regulating unit [9].

1.2 Effects of Radiation on Humans
Radiation is in the air we breathe, the food we eat, the buildings in which we live, and the Earth in which we live. As society continues to evolve, man-made radiation increases radiation levels and potential exposure to humans [10]. Radiation work safety is an effort made to create conditions so that the dose of ionizing radiation that hits humans and the environment does not exceed the specified limit value [11]. One source of ionizing radiation is X-rays which are widely used for medical purposes [12]. The most influential thing in the amount of radiation exposure on the X-ray machine is the time in milliamperesseconds (mAs), the patient's body weight, and the peak voltage in the tube (kVp) [13]. Dosage optimization is very important for the quality and quantity of quality control tests on X-ray equipment. The widespread use of X-rays in the diagnosis and management of patients has led to
increased radiation exposure [14]. Exposure to even small levels of medical radiation is a potential and avoidable public health threat [15]. Especially the organs of children and infants are much smaller than the organs of adults, therefore the amount of energy given will produce a much higher negative dose [16]. There are two types of radiation, ionizing radiation and non-ionizing radiation. Exposure to ionizing radiation often causes a decrease in the immune system, especially with lower doses [17]. Therefore, it is very important that the inspection method using X-ray aircraft ensures that all information obtained can be fully utilized and interpreted with maximum efficiency [18]. The effects of radiation can occur due to acute exposure ie exposure that occurs due to a large single dose of overexposure and chronic exposure ie exposure that can occur due to small doses which are continuously applied for years [19]. The effect of low radiation doses is exposure to radiation which can spread over time which results in the long term [20].

2. Methodology
The method used in this study consists of several stages, namely: software design, hardware design, data retrieval

2.1. Software Design
The design of the tool is done, with a pattern of research process flowcharts used in working on the tools are in Figure 1:

![Figure 1. Flowchart](image)

When the device is turned on, the microcontroller will initialize the program and position the filament in standby. When going to use the tool for X-rays the first thing to do is adjust the kV, mA and S. After it is set, then proceed by pressing the ready button. When ready is reached, the green indicator light will light up, after the ready indicator lights up it can be continued by pressing the exposure button, if the ready indicator is not yet lit, the exposure process will not be able to run. When the process is exposed, the device will produce x-rays, the red indicator will light up. After the timer runs out, the process will end and will return to the initial process.

2.2. Hardware Design
At the hardware design stage, it is carried out by making circuit blocks, which consist of a minimum ATMega328P microcontroller system circuit, kV driver circuit, indicator light circuit.
2.3. Minimum System Series
Component specifications used in the ATmega 328p minimum system circuit are Using ATmega 328p, Using Crystal, Requires a working voltage of +5V, and GND, Using push buttons, resistors 10k, 330, LEDs, and 10uf, 22 pf capacitors.

![Figure 2. Rangkaian minimum system](image)

The minimum series of ATmega 328p microcontroller systems has programmable input/output support and On-Chip RAM. This circuit can be made very flexible depending on the application to be made. In general, a microcontroller requires two elements (besides the power supply) to function: Crystal Oscillator (XTAL), and RESET Circuit.

2.4. kV Driver Circuit
The kV driver circuit serves to control the contactor for the selection of the Kv value from the autotrafo that provides input to the HTT. This circuit will be controlled by Arduino by providing input to the base of the transistor bd139 which functions as a liaison between the relay coil and the ground. If Arduino has HIGH logic, the transistor will be active and the ground relay coil will be connected and the relay active and vice versa. The NO (normally open) legs of the five relays will each get into one of the five contactor coil.

![Figure 3. The kV driver circuit](image)
2.5 Indicator Light Series
When the ready button is pressed, relay R1 is active, the filament heater lights up. In the process of heating the filament, it takes a delay of 3 seconds. When the delay has been reached, the relay R2 is active, the Ready light is on, marking the Expose process can be performed. Then the Expose button is pressed, then the relay R3 is active, the Expose lamp lights up, when the time has been reached then all lights will turn off all.

![Figure 4. A series of indicator lights](image)

2.6 Data Collection Techniques
Testing tool uses a digital multimeter to measure the output voltage (V) that is on the contactor connected to the kV driver circuit when doing the exposure process. Measuring distance using a meter that is done with two conditions, namely without a barrier and there is a barrier, then testing the tool's working system by looking at 3 different indicator lights namely green, yellow, and red during the stand by, ready, and exposed processes.

2.7 Tool Design
In Figure 5 below is a physical form on the tool:

![Figure 5. The physical form of the tool](image)

The tool has a push button as a regulator ON / OFF for the tool. There are three indicator lights on the top of the tool with different colors, namely green for the stand by state, yellow for the ready process, and red for the exposure process. Here is a picture when the tool is run:
3. Results and Discussion

The testing and measurement activities of the tool include several tests, namely:

3.1. Measurement of the Output Voltage on the Tool

Data retrieval on the tool is done by measuring the output voltage on the kV parameter tool when the exposure process is carried out 20 times using a multimeter. Here are the results of measurements on each parameter:

| Tegangan(V) | Rata-rata(V) | Koreksi |
|-------------|--------------|---------|
| 140(60 kV)  | 140,25       | +0,25   |
| 150(65 kV)  | 151,15       | +1,15   |
| 160(70 kV)  | 160,95       | +0,95   |
| 170(75kV)   | 170          | 0       |
| 180(80kV)   | 179,05       | -0,95   |

In Table 1, measurements were made at the voltages of 140, 150, 160, 170 and 180 V. From the above table, the greatest correction values were obtained for the parameters 160 V and 180 V with a correction of 0.95. The smallest correction value is in the 170 V parameter with a correction value of 0 V.
Table 2. Converting V voltage to kV.

| Tegangan(kV) | Rata-rata(kV) | Koreksi  |
|--------------|---------------|----------|
| 60 kV        | 60,13         | +0,13    |
| 65 kV        | 65,58         | +0,58    |
| 70 kV        | 70,48         | +0,48    |
| 75 kV        | 75,03         | +0.03    |
| 80 kV        | 79,53         | -0,47    |

In table 2, the voltage conversion is done by using the equation $y = mx + c$ and the largest correction value is obtained at the parameter 65 kV with a correction value of 0.58 kV and the smallest correction value is at the parameter 75 kV with a correction value of 0.03 kV.

Table 3. Distance measurements (no obstructions)

| No | Jarak(m) | Koneksi(Ya/Tidak) |
|----|----------|-------------------|
| 1  | 2        | Ya                |
| 2  | 4        | Ya                |
| 3  | 6        | Ya                |
| 4  | 8        | Ya                |
| 5  | 10       | Ya                |

Table 4. Distance measurements (with 9.5 cm wall thickness barrier)

| No | Jarak(m) | Koneksi (Ya/Tidak) |
|----|----------|--------------------|
| 1  | 2        | Ya                 |
| 2  | 3        | Ya                 |
| 3  | 4        | Ya                 |
| 4  | 5        | Ya                 |
| 5  | 6        | Ya                 |
| 6  | 7        | Tidak              |

In table 3 the distance measurements are carried out without a barrier with a maximum distance of 10 m with the results of serial communication properly connected. Table 4 measures the distance to the barrier wall with a thickness of 9.5 cm with the result of serial communication error / not connected at a distance of 7 meters.

Table 5. Testing system work tools

| Proses       | Lampu hijau | Lampu kuning | Lampu merah |
|--------------|-------------|--------------|-------------|
| Stand by     | Hidup       | Mati         | Mati        |
| Ready        | Mati        | Hidup        | Mati        |
| Expose       | Mati        | Mati         | Mati        |

In the test table, the results show that the green light is on in a stand-by state, the yellow light when ready, and the red light when exposed. The system works in accordance with the actual system.

4. Conclusion

From the results of the measurement data on the tool "Arduino-Based Wireless X-ray Machine Control System" can be concluded as follows:

1. The average value at the lowest output voltage value of the 60 kV parameter is 140.25 V and for the highest output voltage value at the 80 kV parameter is 179.05 V.
2. The average value of the conversion value in the lowest parameter that is 60 kV is 60.13 kV and the conversion value for the highest parameter that is 80 kV is 79.53 kV.
3. The biggest correction is +1.15 V at 150 V, and the smallest correction is 0 at 170 V.
4. The largest correction in the output voltage conversion value is +0.48 in the 65 kV parameter and +0.03 in the 70 kV parameter is the smallest correction value in the output voltage conversion value.
5. The maximum distance traveled by a 9.5cm wall barrier is 6 meters.
6. The working system of the tool works in accordance with the system with the lights as indicators.

Based on the statement above, the correction value produced on the tool is still within the tolerance range of ± 1 V, and the tool works well according to the desired system.

5. References

[1] F. Suyatno, L. Yuniarsari, S. Syawaludin, and K. Puspiptek, “Perekayasaan Prototip Pesawat Sinar-X Berbasis Mikrokontroler,” Prosiding Pertemuan Ilmiah Rekayasa Perangkat Nuklir. pp. 124–130, 2010.
[2] F. Suyatno, “Aplikasi radiasi sinar-x di bidang kedokteran untuk menunjang kesehatan masyarakat,” SDM Teknologi Nuklir, vol. 1, no. Teknologi Nuklir. pp. 25–26, 2008.
[3] T. O. T. O. T. Rikasjono, E. L. S. Upriyatni, and H. E. B. Udyono, “Radiasi Di Kawasan Batan Yogyakarta,” SDM Teknologi Nuklir. pp. 25–26, 2008.
[4] H. H. I. Kohei Sato, Takashi Ohnishi, Masashi Sekine, “Geometry calibration between X-ray source and detector for tomosynthesis with a portable X-ray system,” Int. J. Comput. Assist. Radiol. Surg., vol. 12, no. 5, pp. 707–717, 2017.
[5] P. Dan and P. Perangkat, “Pembuatan sistem pengendali parameter tegangan, arus dan pew aktu pada pesawat sinar-x,” Pro Siding Seminar Penelitian Dan Pengelolaan Perangkat Nuklir. pp. 367–376, 2013.
[6] S. D Martina ? Susilo, “Uji Kolimator Pada Pesawat Sinar-X Merk/ Type Mednif/Sf-100By Di Laboratorium Fisika Medik Menggunakan Unit Rmi,” Jurnal MIPA, vol. 38, no. 2. pp. 121–126, 2016.
[7] 3 Antoine Rousse, 1 KimTa Phuoc, 1, 2,* Rahul Shah, 2 Alexander Pukhov, 3 Eric Lefebvre, 4 Victor Malka, 1 SergeyKiselev and 2 and Dani’le Hulin Fre’deric Burgy, 1 Jean-Philippe Rousseau, 1 Donald Umstadter, “Production of a keV X-Ray Beam from Synchrotron Radiation in Relativistic Laser-Plasma Interaction,” PHYSICAL REVIEW LETTERS, vol. 93, no. 13, 2004.
[8] P. Yasaan, U. Mengurangi, and P. W. At, “Prolink PIC 1002 IP.,” Prosiding Pertemuan Ilmiah Nasional Rekayasa Perangkat Nuklir. pp. 220–226, 2007.
[9] Z. Abidin et al., “Refurbishing pesawat sinar-x diagnostik eks. litbang batan,” Seminar Nasional Viti. pp. 144–148, 2012.
[10] W. E. Morgan’ and Radiation, “Non-targeted and Delayed Effects of Exposure to Ionizing Radiati I. Radiation-Induced Genomic Instability and Bystander Effec.” 2003.
[11] M. Djoko, Solichin, and Z. Abidin, “Analisis Keselamatan Kerja Radiasi Pesawat Sinar–X di Unit Radiologi RSU Kota Yogyakarta,” Seminar Nasional IV. pp. 679–689, 2008.
[12] H. D. Yunitasari, E. Setiawati, and C. Anam, “Evaluasi Metode Penentuan Half Value Layer (Hvl) Menggunakan Multi Purpose Detector (Mpd) Barracuda Pada Pesawat Sinar-X Mobile,” Youngster Physics Journal, vol. 3, no. 2, pp. 113–118, 2014.

[13] D. S. David J. Brenner, Ph.D., D.Sc., and Eric J. Hall, D.Phil., “Computed Tomography — An Increasing Source of Radiation Exposure,” 2008.

[14] M. Gholami, F. Nemati, and V. Karami, “The evaluation of conventional X-ray exposure parameters including tube voltage and exposure time in private and governmental hospitals of Lorestan province, Iran,” Iranian Journal of Medical Physics, vol. 12, no. 2, pp. 85–92, 2015.

[15] M. D. Michael S. Lauer and Related, “Elements of Danger — The Case of Medical Imaging Michael,” 2009.

[16] A. H. and J. Bremerich, “The danger of radiation exposure in the young.” 2009.

[17] K. S. Yu-Pei Liao, Chun-Chieh Wang, Lisa H. Butterfield, James S. Economou, Antoni Ribas, Wilson S. Meng and I. and W. H. McBride, “Ionizing Radiation Affects Human MART-1 Melanoma Antigen Processing and Presentation by Dendritic Cells,” 2018.

[18] G. N. Hounsfield Central, “Computerized transverse axial scanning (tomography): Part 1. Description of system,” Nippon Jibiinkoka Gakkai Kaiho, vol. 80, no. 10sokai, pp. 1062a – 1064, 1977.

[19] Dewi Widyaningsih1) dan Heri Sutanto2, “Penentuan Dosis Radiasi Eksternal Pada Pekerja Radiasi Di Ruang Penyinaran Unit Radioterapi Rumah Sakit Dr.Kariadi Semarang,” Berkala Fisika, vol. 16, no. 2, pp. 57–62, 2013.

[20] E. Ron and Radiation, “Ionizing Radiation and Cancer Risk: Evidence from Epidemiology Elaine.” 1998.