Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics
Multidisciplinary : Rapid Review : Open Access Journal Vol. 5, No. 4, November 2023, pp.210-216 e-ISSN: 2656-8624

RESEARCH ARTICLE OPEN ACCESS

Manuscript received September 18, 2023; revised September 20, 2023; accepted November 12, 2023; date of publication Nov. 12, 2023
Digital Object Identifier (**DOI**): https://doi.org/10.35882/ijeeemi.v5i4.328

How to cite: Revindo Prima Sulthon Narendra, Muhammad Ridha Mak'ruf, Triwiyanto Triwiyanto, and Yassin Nimir, "Development and Evaluation of a Webcam-Based Digital X-Ray Machine Detector with Variable Current and Light Intensity Settings", Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics, vol. 5, no. 4, pp. 210–216, November. 2023.

Development and Evaluation of a Webcam-Based Digital X-Ray Machine Detector with Variable Current and Light Intensity Settings

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ABSTRACT X-ray images typically appear as film sheets upon development after undergoing chemical processing. To address these challenges, endeavors were undertaken to create digital X-ray detectors utilizing more cost-effective equipment. This approach involves harnessing variations in current and light intensity to discern disparities in image quality. The noteworthy contribution of this study lies in its ability to exhibit inverted images captured through webcam cameras, subject to prior image processing via the MATLAB application. The utilized measurement ranges encompass 20, 32, and 40 mA, while maintaining a fixed irradiation duration of 1 second and varying the illumination intensity across low, medium, and high levels at a constant 60kV setting. The obtained measurements reveal that the X-Ray Image Capture Device can be juxtaposed with images produced by the Philip brand Digital Radiography, evaluated through the acquired Mean Squared Error (MSE) values. The best picture in this experiment is using system parameter settings with kv of 60kV, 20mA and with low light intensity, and using the PH101 phototransitor. Conversely, the least favorable image records an MSE value of 66.4552p^2 under 60kV 20mA conditions, employing the PH101 Phototransistor sensor and high light intensity. In summary, the outcomes of this study indicate the efficacy of the tool in capturing X-ray images.

INDEX TERMS X-Ray machine, Webcam, MATLAB, MSE

I. INTRODUCTION

Conventional X-ray imaging has conventionally hinged upon the utilization of film sheets to yield outcomes. Nevertheless, film-centric X-ray approaches exhibit certain constraints, including the challenge of facile image manipulation and the occurrence of impediments such as pronounced obscurity, luminosity, and interference in the generated outputs. [1][2][3]. Digital X-ray machines enable image editing, allowing for adjustments to be made to enhance image quality. Furthermore, the images can be stored as a database, facilitating easy access and retrieval whenever required. They can also be conveniently printed or transmitted via local internet networks to a doctor's personal computer, enabling efficient analysis of a patient's condition. These capabilities make digital X-ray machines a significant advancement in medical technology [4][5][6]. Despite the advantages, one of the major drawbacks of digital X-ray machines is their high cost, making them inaccessible for some healthcare facilities. Additionally, the operation of these machines demands a significant investment in human resources for training and maintenance. [7]. These new digital X-ray devices employ voltage variations and sensors to assess and differentiate image quality. Factors such as tube voltage, time, and distance play a crucial role in determining the quality and quantity of the resulting images during the irradiation process. By utilizing these parameters and employing cost-effective technologies, researchers aim to create digital X-ray machines that are more affordable while maintaining acceptable image quality.[8][9] With these machines have prompted the development of cheaper alternatives. By leveraging voltage variations and sensor technology, researchers are striving to create more affordable digital X-ray devices without compromising image quality. These advancements hold great potential for expanding access to high-quality diagnostic imaging in healthcare settings.[10]

In 2015, Luiz Antonio P. dos Santos and his colleagues conducted a study on the comparison of phototransistors, ionization chambers, and photodiodes as x-ray beam dose detectors. According to him, the phototransistor sensor is the strongest candidate as a detector for x-ray diagnostic purposes because it has small dimensions, high output current, and does not require high voltages [11]. In 2021, Edrine Damulira conducted research on comparing the performance of PH101 photodiodes and cold white LED which is based on xray radiographic examination. According to PH101 photodiode and cold white LED, the precision is 84.8% and 85.5% [12]. In 2016, Kusminarto conducted research on the development of a phototransistor-based X-ray detector PH101, according to which this type of phototransistor could be used for X-ray light sensors using darlington gain [13]. In 2016, Jawaaz Ahmad and Romana Yousuf conducted research on measuring low light intensity using a Light Dependent PH1101ensor. According to him, the phototransistor sensor can be used as a sensor for this research [14]. P. Zhang conducted research on flat panel detectors which are intended as radiation gas detectors [15]. P. Bernhard, A. Brogna, S. Caiazza et al designed a device that constructs a gas detector in an area with a wide pattern [16]. In 2021 Yuanhong Gao, Yongshuai Ge, Xinwei Wang et al conducted According to that study's findings, the majority of modern X-ray detectors use device design with poor or no gain energy conversion. As a result, this study uses the high gain method as a new x-ray sensor. X-ray phototransistor, different from traditional detectors, this is because the concept uses modulation that is more efficient so that it gets a tight density that allows little noise to occur[17]. Gerald K. Ijemaru, Augustine O., and his friends looked at Matlab-based imaging process analysis in 2021. He claims that different image processing procedures can be accurately documented and repeated using Matlab. Additionally, compared to other cutting-edge image processing software, the Matlab-based image processing technique is more sophisticated [18]. Several other studies state that the MATLAB application is very possible to be used as an image processing application. In this case the use of MATLAB as grayscale image processing [19][20]. Several other studies conducted research on the use of digital radiography as a technology that is up-to-date and can be further developed in accordance with the times [21][22][23]. Researchers Ravneet Kaur, Ravtej Singh Sandhu, Ayush Gera, and Tarlochan Kaur using MATLAB to increase the degree of deformity in panoramic xray examinations. This study utilizes MATLAB to apply learning algorithms to x-ray images in dental panoramic where the algorithm used is the gradient method. For edge detection of the region of interest, JPEG-format datasets of digital panoramic dental radiographs are used. The outcomes demonstrate the successful application of the developed methodology [24]. In a 2020 study conducted at the UNNES medical physics laboratory, Susilo, Purwaningsih, Darsono et al examined research on camera synchronization with x-rays through an x-ray tube in a digital system. The researchers utilized a DSLR camera as the X-ray image capturer. However, the study highlighted certain challenges associated with using DSLR cameras, including their large dimensions that require significant space and the high cost, making them unaffordable for many. These limitations emphasize the need for more compact and cost-effective alternatives in digital radiography systems [25].

The research conducted giving light on a significant gap in the exploration of digital detectors that rely upon cameras and PCs for data processing. Although certain studies have been carried out, the costs associated with manufacturing this technology remain relatively high. As a result, there exists an urgent need for ongoing investigation and advancement in this domain to enhance both accessibility and affordability. By tackling these obstacles, researchers can pave the path for a broader adoption of digital detectors, potentially unlocking their versatility for various applications spanning industries such as surveillance, imaging, and scientific research.

The scientists want to utilize a webcam camera to take x-ray photographs, which builds on earlier studies. They employ three distinct lighting conditions—low, moderate, and high—and modify the mA parameter values to achieve this. The key goal is to reduce the system's cost while maintaining the ability for the camera to capture the fluorescence screen's picture. The image processing capabilities of Matlab will then be used to assess the generated grayscale values at various mA levels. This research project intends to create meaningful data on the usage of webcam cameras in x-ray imaging with the potential to provide economical solutions for both medical and scientific applications.

II. MATERIALS AND METHODS

A. EXPERIMENTAL SETUP

This investigation produced X-rays using Philips Digital Radiography. Data collection uses 3 types of mA, namely 20, 32, and 40 mA with 3 condition of light intensity, there are low, medium, and high and use the trigger sensor is Phototransistor PH101(connected in series with a 1m resistor and a 0.5A diode of type 4007). This research uses fluorescence screen to convert X-Rays into visible light. Phototransistor PH101 as shutter sensors. Logitech webcam camera as image capture. Infrared to provide lighting for the camera. Arduino UNO as a microcontroller. Because of its high density, a solid iron padlock was used in this experiment so that the findings could be readily viewed. A padlock is placed on top of the tool that has been manufactured under the x-ray tube at a distance of 60 cm to gather data. Then, data was gathered nine times with mA changes of 20, 32, and 40 as well as various light intensities, including low, medium, and high. The findings of Philips brand digital radiography are then compared with all of these data, and the MSE value is calculated.

B. THE DIAGRAM BLOCK

In FIGURE 1 explains the block diagram of the tool system. Parts of Philip's Computed Radiograhy (CR) radiography apparatus are shown in the mA, Second, kV, and X-Ray setting blocks.

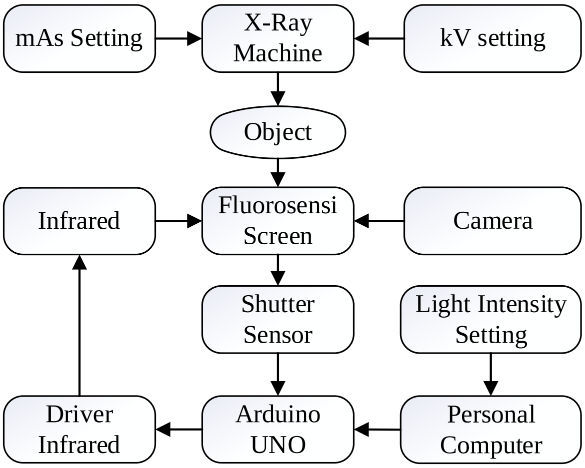


FIGURE 1. The diagram block of digital detector

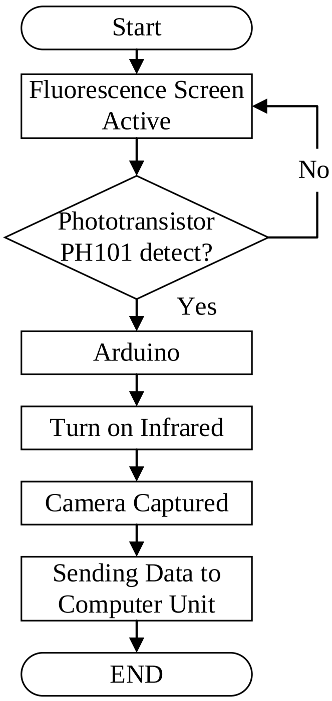


FIGURE 2. Flowchart of the digital detector

If so, a solid object was utilized in this block. Then, in the infrared block, tools will be created for the screen fluorescence, camera, shutter sensor, infrared driver, arduino, PC, and infrared intensity settings and sensors. Setting mA must come first, followed by setting kV with a specified value and a range of values in the control table. On a PC, the shutter sensor and infrared light intensity are chosen.. Following the creation of X-Rays by the radiograph, some of the rays are absorbed by the object and the remainder is sent to the screen to be converted into visible light. The visible light is then captured by the shutter sensor and processed by the microcontroller to tell the infrared driver to turn on infrared and also send a signal to the PC so that the camera can capture visible light from the screen. The findings of the camera's picture capture will then be processed in Matlab.

C. THE FLOWCHART

FIGURE 2 Firstly, let's take a closer look at the detailed flow chart of the detector. Once the object emits visible light, the fluorescence screen, being a key component, promptly generates a luminous display. Subsequently, the highly sensitive shutter sensor swiftly detects the emanating light and effectively triggers the meticulously programmed Arduino microcontroller. With its exceptional computational capabilities, the Arduino microcontroller promptly initiates a series of precisely timed instructions, enabling the camera to proficiently capture the visually striking images produced by the vibrant fluorescence exhibited on the screen.

The advanced infrared technology plays a critical role in enhancing the image capture process, and the Arduino microcontroller effortlessly activates it simultaneously as part of its unmatched capabilities.

By employing the invisible infrared spectrum, it effectively enhances the overall quality and clarity of the captured images. This synchronized activation of the infrared feature ensures optimal assistance to the camera in capturing the vibrant and intricate details presented by the fluorescence screen. Following the successful capture, the meticulously.

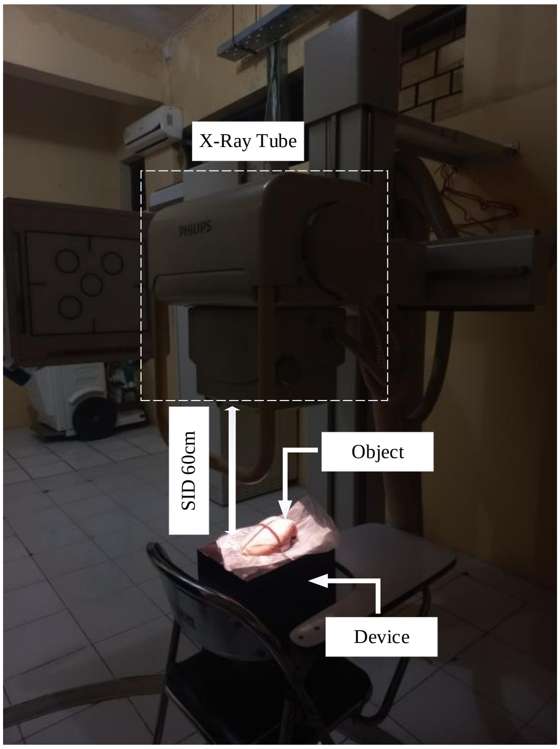
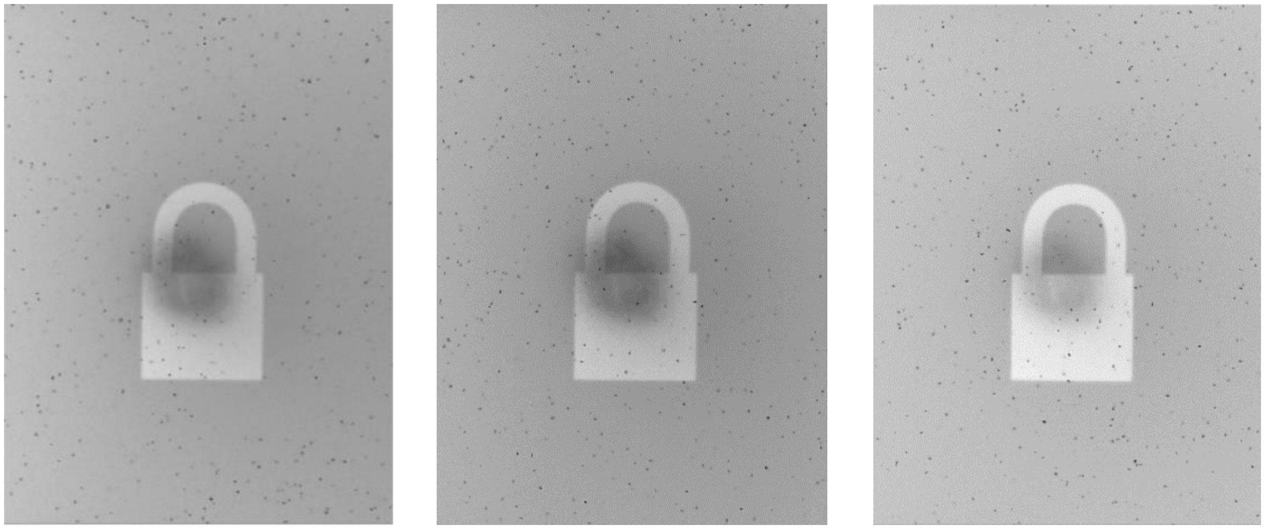


FIGURE 3. Flowchart of the digital detector



(a) (b) (c)

FIGURE 4. Result image of setting system PH101 (a) 60kV 20mA low, (b) PH 60kV 32mA low, (c) PH101 60kV 40mA medium

D. Data Collection

The following content below is an example of a picture of data collection in this study, while researchers used the Philips brand DR tool on campus. FIGURE *3* shows that the distance (SID) between the device and the x-ray tube is 60cm. The object is placed on top of the device, and then the room lights used for data retrieval are turned off. Then it was analyzed using Matlab. After the application is run and the program initialization occurs, Matlab will wait for the image data to be sent by the camera to Matlab. After the image is entered, next is the image processing process, where it will be converted into a gray image, which will then be converted into a negative image. The next step is to calculate the MSE value by comparing the image from the tool with the image from the DR Philips brand to see the effect of the mA setting on image quality.

E. Data Analysis

The process of data analysis involves the interpretation of processing results, especially the results obtained from Matlab image processing. This analysis focuses on comparing image output from various conditions of light intensity, ranging from dim, medium, and bright. Evaluation based on image quality uses mA settings of 20, 32, and 40, with an emphasis on MSE (Mean Squared Error) values. the MSE formula used in Eq. (1) :

$$\mathrm{MSE} = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left|\left(f(x,y)\right), -g(x,y)\right)^2\right| \quad (1)$$

Lower MSE values indicate superior image data quality. By assessing and comparing these values, we can determine which lighting intensity and mA setting produces the best image results.

III. RESULT

In this study, the X-Ray image capture tool has carried out a comparative test of MSE values using Philips brand digital radiography (DR) tools. Following are the results of the study as shown in TABLE 1.

TABLE 1
MSE value of 60kV 20mA setting system

Setting System	MSE Value
PH101 60kV 20mA LOW	2.5420p^2
PH101 60kV 20mA MEDIUM	56.3367p^2
PH101 60kV 20mA HIGH	64.4333p^2

TABLE 1 explains that there are results of the calculation of the MSE 60kV 20mA setting with PH101 sensor. It can be seen that the smallest MSE value is the low condition of intensity light with a value of 2.5420p^2. As we know that the smaller the MSE value, the better because it is similar to the image used as a comparison. The image results from low condition of intensity light are shown in FIGURE 4(a). These results have already gone through the image processing process to become negative images in the MATLAB application.

TABLE 2
MSE value of 60kV 32mA setting system

Setting System	MSE Value
PH101 60kV 32mA LOW	41.1077p^2
PH101 60kV 32mA MEDIUM	61.1152p^2
PH101 60kV 32mA HIGH	57.5578p^2

TABLE 2 explains that there are results of the calculation of the MSE 60kV 32mA setting with PH101 sensor. It can be seen that the smallest MSE value is the low condition of intensity light with a value of $41.1077p^2$. As we know that the smaller the MSE value, the better because it is similar to the image used as a comparison. The image results from low condition of intensity light shown in FIGURE 4(b). These results have already gone through the image processing process to become negative images in the MATLAB application.

TABLE 3
MSE value of 60kV 40mA setting system

Setting System	MSE Value
PH101 60kV 40mA LOW	$52.8779p^2$
PH101 60kV 40mA MEDIUM	$23.1484p^2$
PH101 60kV 40mA HIGH	$66.4552p^2$

TABLE 3 explains that there are results of the calculation of the MSE 60kV 40mA setting PH101. It can be seen that the smallest MSE value is the meidum condition of intensity light with a value of $23.1484p^2$. As we know that the smaller the MSE value, the better because it is similar to the image used as a comparison. The image results from PH101 shown in FIGURE 4(c). These results have already gone through the image processing process to become negative images in the MATLAB application.

IV. DISCUSSION

The measurement results from different X-ray settings, namely 20mA, 32mA, and 40mA, show varying Mean Squared Error (MSE) values. Through several attempts of data collection, the results were obtained under the 20mA setting, the best MSE value achieved was $2.5420p^2$. These results were obtained using the Photodiode PH101 sensor and low light intensity settings. At the 32mA setting, the best MSE value was recorded at $41.1077p^2$. When the X-ray setting was adjusted to 40mA, the best MSE value achieved was $23.1484p^2$. From all the data collected, the best MSE value was $2.5420p^2$. The best results are using system settings with 60kV 20mA and low light intensity. These findings show that the combination of higher X-ray settings, proper sensor selection, and moderate light intensity settings yields the most accurate and reliable results with the lowest MSE. This information is invaluable for optimizing X-ray measurements and ensuring high-quality imaging results.

The image results of this study according to Susilo, Purwaningsih, Darsono et al who researched capture of X-ray image results using a DSLR camera. Additionally, the device utilized in this study is more cost-effective and affordable compared to other studies. This combination of superior image quality and affordability makes this research particularly notable in the field[25].

This study was compared with Yuanhong Gao, Yongshuai Ge, Xinwei Wang, et al., for which they used a detector that is very elastic and thin but also very sensitive to light. However, it raises a drawback, namely the appearance of spots that are scattered over the entire surface of the image. This distinction underscores the significance of the current study's approach, which not only emphasizes cost-effectiveness and operator-friendly procedures but also aims to mitigate issues like image noise, contributing to the advancement of X-ray detection technologies[17].

Similar to the approach undertaken by Gerald K. Ijemaru, Augustine O., and their colleagues, this study employs MATLAB for image processing. However, it reveals that while MATLAB can serve as an image processing application, further advanced editing and processing are necessary for optimal performance, diverging from the notion of its inherent perfection[18]. The image of the results of this study outperforms previous research, showing superiority. In addition, the device used in this study is more cost-effective and affordable compared to other studies. The combination of superior image quality and affordability makes this research stand out in the field. Despite all these advantages, the results of this study are disturbed by the presence of scattered grain noise in the image. These weaknesses hindered the overall quality and reliability of the study findings, indicating the need for further refinements and improvements in the image processing techniques used. This research brings significant benefits to the wider community through the development of affordable digital detectors. By using less expensive devices, hospitals can reduce costs, enabling them to improve services and better serve the needs of the community. These innovations have great potential to improve the accessibility and overall quality of healthcare, ultimately benefiting the larger population.

V. CONCLUSION

In summary, this study aims to develop an X-ray image capture tool using an Arduino-based webcam and the MATLAB application. By investigating the mA settings and the parameters of the light intensity, the authors succeeded in making a system. Through observation, experimentation, and measurement data, it was determined that the Phototransistor PH101 sensor could trigger the camera. Besides that, this research also proves that infrared light cannot clarify image quality and even worsens image quality. This research provides valuable insights into sensor and infrared capabilities to inform future device improvements. Among the 9 data points collected, the best image results were achieved with a 60kV 2mA setting, utilizing the Photodiode PH101 sensor under moderate light intensity. This is evidenced by the Mean Squared Error (MSE) value listed which is 2.5420 which indicates that the smaller the MSE the better the image quality. The hope for future research is to address several key areas. First, efforts will be directed at noise decomposition in image results to improve overall image quality. Additionally, there was a desire to optimize the capture time to achieve speeds under 1 second. Real-time image processing capabilities will be integrated for live analysis. In addition, reducing the error rate compared to Phillips brand DR tools is a priority. Finally, the wireless functionality of the device will be expanded, enabling increased mobility and convenience in X-ray shooting.

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