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An Improved Design of Flat Panel Detector with Phototransistor PH101 Analysis of The Tube Voltage Setting

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ABSTRACT The intensity and quality of the X-Rays a patient receives is determined by the exposure factor. Voltage (kV), Current (mA), Time (seconds), and tube-to-film distance (FFD) are exposure factors that can be controlled and determined. The key factor that can determine the quality of X-Rays is the tube voltage (kV) which affects the X-Rays to penetrate objects. The purpose of this research is to improve image quality and relatively affordable manufacturing costs by obtaining the difference in the detector catch value between dark and light by utilizing the response of the PH101 phototransistor sensor. The contribution of this research is that the system can display grayscale and numeric on a 16x16 pixel matrix using the Matrix Laboratory (MATLAB) application. This research can convert images taken from analog data after measuring the phototransistor PH101 on X-Rays. The measurement settings used are 50, 55, 60, and 70kV, with a tube current of 40 mA and an irradiation time of 1 second. The measurement results show that the Flat Panel Detector Design can respond to differences in doses and objects. This research shows that a Flat Panel Detector and a Phototransistor PH101 sensor have been successfully made which can be used to capture X-Rays so that the black level of the film can be determined.

INDEX TERMS Expose Factor, X-Ray, kV, Greyscale, MATLAB.

I. INTRODUCTION

X-Ray radiation is a form of electromagnetic wave energy that is used for disease diagnosis and health therapy[1]. However, if there is an error in setting both voltage and current on the operating system in the application of diagnosis and therapeutic purposes, it can harm body tissues and provide inaccurate information about the patient[2]. Exposure factor is a factor that determines the intensity and quality of X-Rays received by the patient[3]. Exposure factors that can be controlled are: tube voltage (kVp), tube current (mAs), irradiation time (second), and X-Ray tube distance to film (FFD)[4]. The key component that determines the quality of X-Rays is the tube voltage (kVp), which affects the capacity of X-Rays to penetrate objects in their path[5]. The presence of blackish differences between many radiographic locations indicates that the tube voltage (kVp) has an impact on the resulting radiographic contrast[6]. To be able to produce radiographs that provide as much information as possible, optimal radiographs are needed[7]. Radiographic quality includes density, contrast, sharpness and distortion, it is necessary to make efforts to suppress factors that can reduce radiographic quality[8][9]. The greater the kV, mA, the time given can reduce the contrast, quantity, and brightness of the radiographic image[10]. Therefore, efforts were made to develop detectors to detect tube voltages with their respective advantages and disadvantages. Research conducted by Kazuhisa Yamamura and Kenichi Sato in 2013 on the use of photodiode sensors placed in a matrix form to form a data matrix. However, the pixels used are too large, it will damage the image data[11]. Research conducted by Muhammad Irsal in 2014 on studying the effect of tube voltage and time varying current, which causes consequences due to the interaction of X-Rays with human body cells, so the dose given to the patient is very important in medical imaging to avoid excessive exposure. no need. Consequently, it is imperative to offer traceability of measurements in diagnostic and interventional radiology for dosimetry procedures[12]. To replace conventional film into a cassette detector in the form of a Flat Panel Detector, Wei Gao and Wen has made it by using TFT as a detector to capture and convert into visible light. Opening new knowledge that all types of photodetectors made of silicon can capture X-Ray light[13][14]. According to Yuan and Gao in 2021 X-Ray phototransistors allow for receiving and amplifying high signals and low noise. The use of ultrathin phototransistors also provides high flexibility and high resolution at an affordable price. From this study it can be concluded that phototransistors can be used to capture X-Rays [15]. The 16x16 phototransistor array providing video output from the common collector electrode, with the emitter connected to the vertical address strip and the base capacitively coupled to the horizontal strip, has proven advantages in ease of fabrication and operation[16]. Meanwhile, in 2017, Eif Sparzinanda investigated the effect of exposure factors on radiographic image quality as well. Increases in tube voltage, current, and time decrease the contrast, quantity, and brightness of the radiographic image. However, in this study, the object used was a water phantom that was inserted into a plastic bag[17]. In 2017 Ramacos Fadela made a design of a kV detector on changes in X-Ray intensity which aims to determine the sensitivity of the phototransistor, the detector sensitivity obtained is 0.037mV with an offset of 130mV. However, in this study, the Darlington circuit is still used, which is a reinforcement that combines 2 transistors, one of which is less affordable and difficult to find[18][19]. Research conducted by Edrine Damulira in 2020 to find the best Led color to absorb X-Rays by changing the irradiation angle, kVp, mAs, surface distance and the size of the absorbed dose. As a result, cold white LED are the best at absorbing X-Rays [20]. Research on X-Ray detectors from Kusminarto made a research in the form of X-Ray detectors using a phototransistor with Darlington amplification to examine the active regions of horizontal and vertical X-Rays. However, this study only measures the ability of the phototransistor to capture X-Rays, not as a detector to produce images[21][22]. Research conducted by Damulira uses a BPW34 type Photodiode as a detector to capture X-Rays. This study also discusses the comparison between BPW34 photodiode and LED Strip as a sensor to capture X-Rays, but in this study only measures the sensitivity of these two components in capturing X-Rays, not as a detector measure and accuracy of the tube voltage [23]. In 2019, According to Atina, the MATLAB program is being developed for medical imaging technology, specifically digital radiography. Since the use of digital radiography is comparable to expensive, the results obtained with the MATLAB application are only duplicated by the hospital. As a result, the use of MATLAB in this application will almost certainly reduce the error of the examiner's analysis because the gray level of the image can be determined correctly[24]. Then in 2021 Rois Amin and Fajar Wahyudi conducted a research on a replica of the Arduino Photodiode-based Flat Panel Detector with an 8x8 pixel field area aimed at capturing X-Ray luminescence. However, there is still a gap between the photodiodes which makes the image imperfect [25][26].

Based on the results of the research above, the authors conclude that the sensors used are often difficult to find and expensive. the diameter is also very large so that the image quality is not good. In addition, a small field area will make the image more unclear. This study aims to design a flat panel detector using Phototransistor PH101 with kV setting parameters. Phototransistor sensor PH101 which has a diameter of 3mm smaller than the Photodiode BPW34, it is hoped that the space between the sensors is close to each other will improve image quality. Using a larger 16x16 matrix than previous studies will clarify the image. Phototransistor PH101 is used to capture X-Rays at an affordable price. Using different kV settings and displayed using MATLAB.

II. METHODHOLOGY

A. DATA ACQUISITION

The instrument used in this study was a Philips Digital Radiography (DR) radiograph. While the material used as a Phantom is an iron plate in the form of keys and key chains. The processing of the data taken is the value of the PH101 analog phototransistor which is obtained when the sensor hits the X-Ray beam. The analog value data obtained is 8 bits or 0-255 because the analog value can be converted to greyscale where the analog data will become image data through grayscale conversion.

B. DATA COLLECTION

This study uses a PH101 phototransistor sensor to capture X-Rays and uses the MATLAB application as an image converter from analog data to a greyscale visible image. This study took data 3 times, taking data at 50kV, 55kV, 60kV and 70kV settings which then converted the data into xlx. Or xlxs in Microsoft Excel and then entered in MATLAB. This study was designed using experiments with quantitative methods. By getting analog data from several kV settings, with scanning measurements starting from analog pins A0 to A15. The captured analog data will be processed into ADC data and then entered into excel with the xlx./xlxs format then entered into MATLAB which produces a greyscale image.

C. DATA PROCESSING

Exposure of the object is done by preparing tools and materials, placing the object above the middle of the fluorescent screen that has been placed on the module. The principle of an intensifying screen is that the material absorbs X-Ray radiation and re-emits it in the form of visible light[27][28]. Then adjusting the distance of the object from the tube to 60 cm with the irradiation field area following the matrix area of 16x16 pixels. The exposure factor is regulated by varying the tube voltage of 50 kV, 55 kV, 60 kV, 70 kV and a constant time current of 20 mAs.

This study uses a PH101 Phototransistor sensor that functions as an X-Ray capture. The sensor output enters the voltage division circuit which then goes to the Arduino analog pin. Arduino Mega 2560 as controller and controller. Arduino output in the form of a serial monitor.

D. DATA ANALYSIS

After getting the image data before being given an object and after being given a phantom object. There are still white patches from unnecessary data. To eliminate unnecessary data, an equalization table is needed which is obtained from the data after being shot with a phantom and data taken before being given a phantom. Then the data is taken and made a table to be compared.

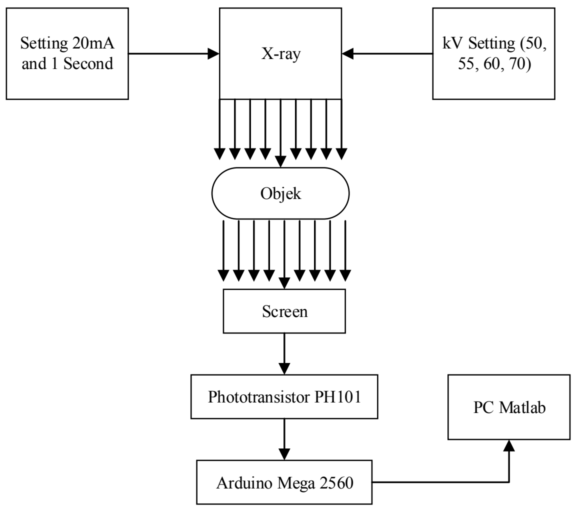


FIGURE 1. Blok Diagram of Flat Panel Detector Using Phototransistor PH101

In FIGURE 1 it is explained that when the detector is turned on, the power supply will provide voltage to the microcontroller but no data has been captured by the phototransistor. When the radiographer provides X-Rays where some of the rays are absorbed by the object and the rest is forwarded to the screen to be converted into visible light, then captured by the phototransistor and then processed by the microcontroller into a data matrix. After several times of capturing images, the results will be processed and displayed to a PC via a microcontroller via cable. Data retrieval used is the scanning method on each sensor with a 16x16 matrix 3 times at each kV setting with a fixed mA. So that each sensor can be taken numerical data and converted into 8 bit gray scale data. The radiograph in FIGURE 2 explains that when the tool is turned on in the initial conditions.

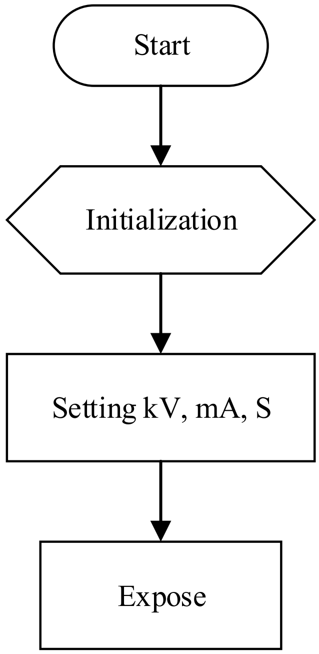


FIGURE 2. Flowchart X-Ray Digital Radiography

An initialization process occurs. The selection of Kv and mA settings and also the length of time, in this study mA and time were set at constant values then kV would be set at values of 50 kV, 55 kV, 60 kV, and 70 kV. After obtaining the desired setting, it will go to the next stage, namely exposure to emit X-Rays which will be captured by the phototransistor detector. In FIGURE 3 when the device is started or has been turned on, the sensor is in standby, after the X-Ray has been exposed, the sensor will detect the X-Ray, if the sensor does not detect the X-Ray, it will return to standby. If the sensor has read the X-Ray tube voltage value, ADC data processing will be carried out because the voltage value will be processed using a microcontroller with 10 bit data, after the data is processed, the data will be sent to a PC via cable and converted in MATLAB to 8 bits to be converted into a gray scale image.

FIGURE 3 and FIGURE 4 explains that the process that occurs uses the MATLAB application as data processing. When the application is opened, the program initialization occurs. The data received is in the form of 16x16 matrix data, then processed into 8-bit grayscale data which has a different level of blackish color according to the data held, namely from 0-255 which this data will be combined into an output image with JPG format using the Conversion Data Matrix to method. JPG Grayscale displayed on PC.

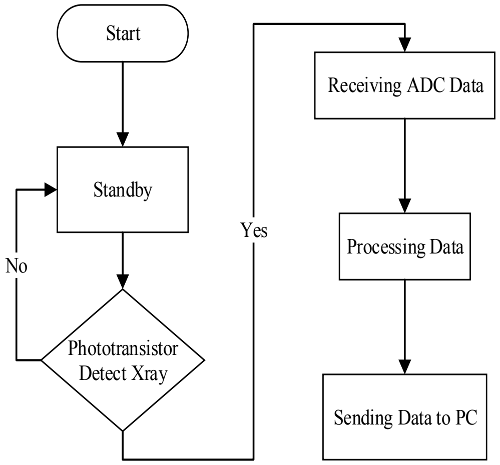
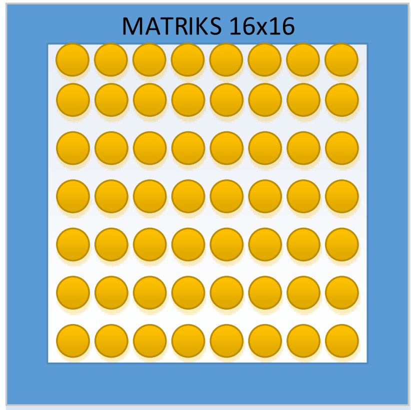


FIGURE 4 Flowchart Detector



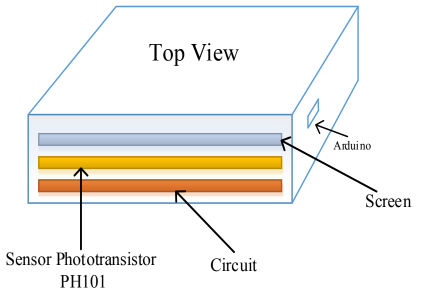
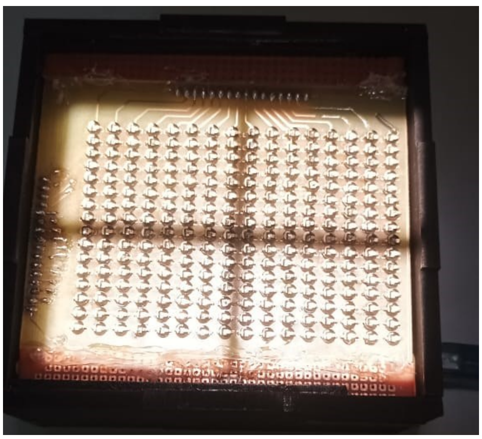
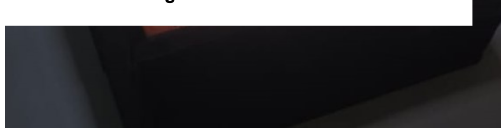


FIGURE 3. Mechanical Diagram of Flat Panel Detector



(a)



(b)

FIGURE 6. image of a module that is illuminated by a collimator beam (a) led array, and (b) an object capture

FIGURE 5 is a mechanical diagram of the flat panel detector design system which consist of sensor phototransistor PH101, circuit layer, a screen layer, and and Arduino ciruit. FIGURE 6 is an example of an image which illuminated by a collimator X-ray beam. FIGURE 6(a) shows the LED array, and FIGURE 6 (b) shows an object which capture by X-ray beam. The illustration of data collection of the proposed design is shown in FIGURE 7.

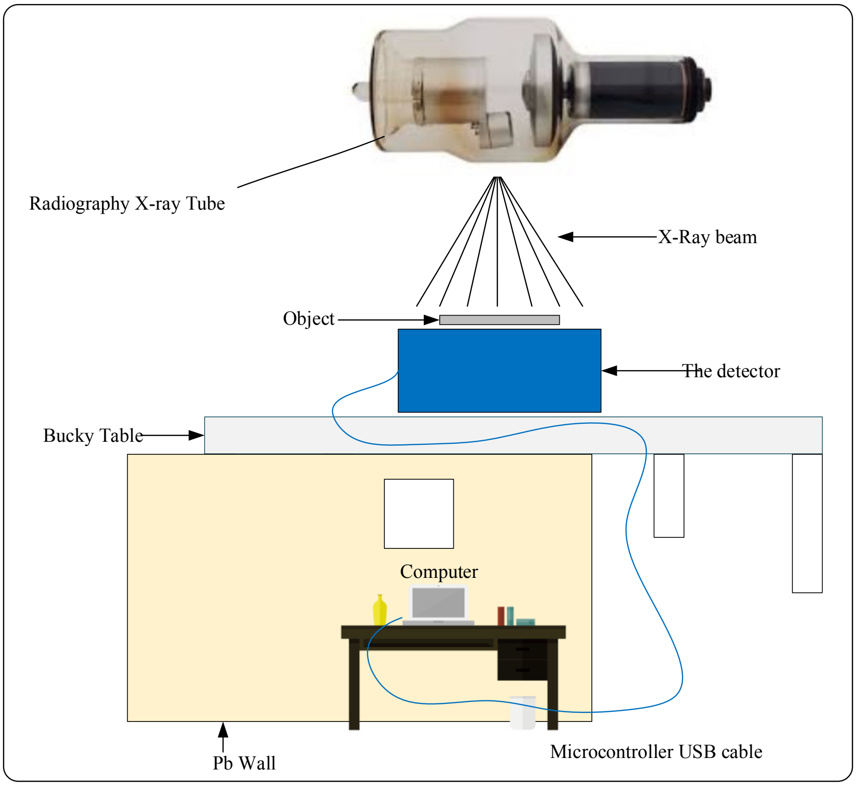


FIGURE 7. **Illustration of data collection consisting of an x-ray machine that emits x-rays to the sensor, phantom object, module design, and a PC placed behind a PB wall**

III. RESULT

The design of this module is carried out using Phototransistor PH101 with a matrix of 16x16 pixels or as many as 256 pieces. Data collection is done by placing the module on the bucky table with a distance of 60cm from the x-ray machine as illustrated in FIGURE 6. This is done so that the phototransistor sensor gets optimal x-rays. The object used uses an iron keychain and a key. FIGURE 8 below is a picture of the finished analog circuit. At the top of the sensor before being given a phantom, it must be given an intensifying screen which functions to convert the X-ray beam that penetrates the object into visible light and will interact with the film to form a latent image.

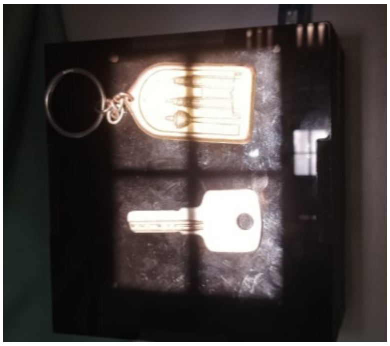


FIGURE 6. **Top View Detector Flat Panel Module Design with Phantom Key Plate and Key Holder.**

In this study the authors used the indirect conversion type flat panel detector scheme method. This is because the x-rays that hit the detector will be changed to light using an intensifying screen. Then, the visible light produced by the screen will be converted into a voltage by the phototransistor PH101.

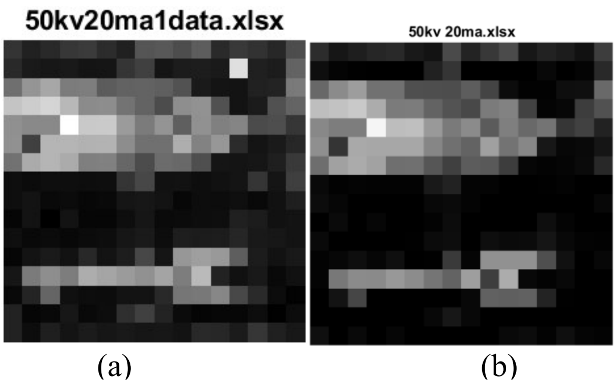
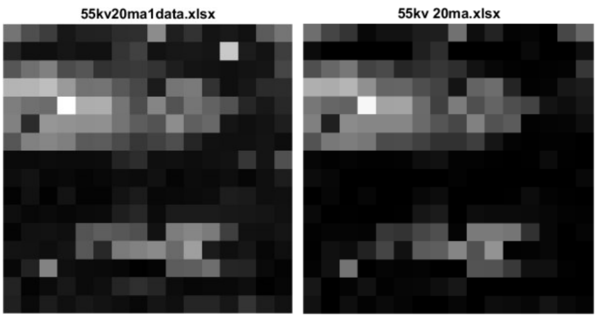


FIGURE 7. **Result of exposure 50kv 20ma (a) result before equalization (b) result after equalization.**

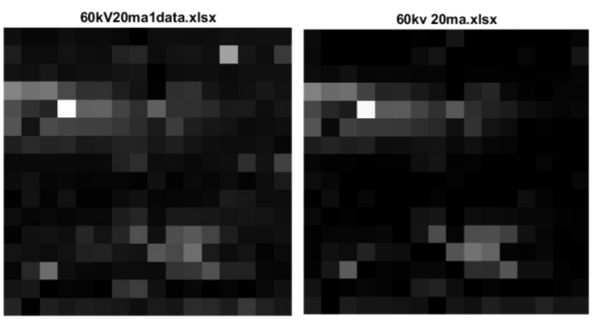
Image quality analysis is carried out based on image visualization (observation) parameters which include contrast and image sharpness. The size of the radiographic image obtained is 16 x 16 pixels with 8-bit resolution, which is displayed and saved in PNG Image (Portable Network Graphics) format. The results of each radiographic image of the key phantom and iron plate that have been exposed are as as shown in FIGURE 9. Sharpness is the ability to show a clear boundary between two areas that have different densities. FIGURE 9(a) shown in the image shows a good gradation, namely the difference between bright white to gray black and the difference between the phantom object and the area around the object. The contrast of FIGURE 9(a) is classified as a good contrast image because it shows a wide range of gray values without a dominant gray value, while for FIGURE 9(b) after equalizing the object is more clearly visible because unnecessary points can be removed.



(a) (b)

FIGURE 8 Result of exposure 55kV 20mA (a) result before equalization (b) result after equalization

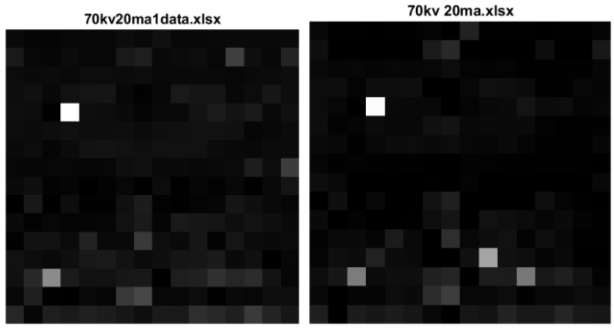
It can be seen in the radiographic image of FIGURE 10(a) that the object is not very clear, but the sharpness of the edges of the object and parts of the object can still be detected. This image has low contrast because the resulting image tends to be dark, so it is quite difficult to distinguish between objects and backgrounds. While for FIGURE 10(b) after equalizing the uneven background part disappears and the object becomes clearer because there are no gray black spots scattered on the image.



(a) (b)

FIGURE 9 Result of exposure 60kV 20mA (a) result before equalized (b) result after equalized

It can be seen in the radiographic image of FIGURE 9(a) that the object is not very clear, but the sharpness of the edges of the object and parts of the object can still be detected. This image has low contrast because the resulting image tends to be dark, so it is quite difficult to distinguish between objects and backgrounds. The background in FIGURE 11(b) looks flatter with black than the FIGURE 9(a).



(a) (b)

FIGURE 10 Result of exposure 70kV 20mA (a) result before equalized (b) result after equalized

The phantom image visualization in FIGURE 12(a) and FIGURE 10(b) of the object are not visible. Has a very low contrast and sharpness (poor) because the resulting image looks dark so that the object is not visible from the background. The decrease in contrast and sharpness is caused by the higher value of the tube voltage. Changes in X-Ray tube voltage affect the gray level of the resulting radiographic image. The higher the voltage used, the lower the gray level produced[29].

The bright area in the X-Ray phantom image represents objects with more tightly tightened structures and has a large absorption rate that is influenced by changes in tube voltages to the quantity and quality of X-Rays. This means that there is an interaction between objects and X-Rays when passing through the object. Therefore, most X-Rays are absorbed by objects, only a few are transmitted, and X-Rays are produced. Picture of a dark ray. A darker area represents the object with a thinner structure, but less X-Ray absorption. Thin objects transmit more X-Rays and absorb less X-Rays, produce brighter colors in the image produced.

A good quality radiographic image is an image that is able to provide clear information about the object or organ being examined[30]. Histogram 3 and histogram 4 are dark images, so no information can be obtained from the image. Images that are outside the object, the value of the degree of gray in the range 0 to 5. However, the gray level distribution for histogram 3 and histogram 4 has a different distribution for each histogram. Histogram 3 is a display of the gray level of image 9(a) which has a gray level position at 0 to 30, while histogram 4 is a display of gray levels of image 10(a) which has a gray level position of 0 to 15.

At a setting of 50 kV the resulting image has a bright contrast, when given an object the affected part of the object will have a lighter color. In parts that have different thicknesses at this point the tool has not responded to the difference in thickness. At 55 kV settings the resulting image has a darker gray level than 50 kV but the difference is not too noticeable. The object at this point can already be identified by an edge that looks different from the part that is not exposed to the object. For parts of the object that have different thicknesses at this point, the difference is still not clearly visible, the difference is identified by the edges that look different from the part that is not exposed to the object. For parts of objects that have different thicknesses at this point, the difference is still not clearly visible.At the 60 kV setting, the resulting image already has a gray color which is still quite bright but darker than the previous setting. The object has also been identified well but the difference in thickness is still not clearly visible. At the 70 kV setting, the resulting image has a dark gray color. Objects can be identified properly and the difference in thickness can be seen.

IV. DISCUSSION

A. SENSOR HISTOGRAM ON MEASUREMENT OF KV BEFORE ADJUSTMENT

By using the MATLAB application, the histograms are obtained as shown in Figures below. Based on the actual type of distribution, the histogram tends to the left for all variations in the number of images, so the image tends to be dark.

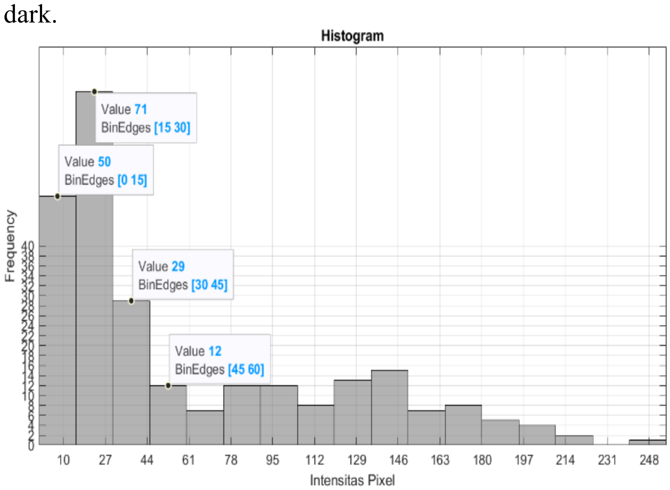


FIGURE 11 Histogram 1 Gray level 50kV 20mA Before Adjustment

In histogram 1 FIGURE 13, it can be seen that there are two regions of the gray level distribution weight, starting from the pixel position 0 to 30 which shows a black background. And position 45-120 is the location of the phantom object. In the histogram, the gray level at position 45-120 is an area where it is still possible to obtain information about the image. The distribution of gray level histogram in Figure 9 is fairly even to the left towards the black area. From this gray level histogram, the image has a fairly good brightness level. Histogram 2 is the gray level of FIGURE 10(a). The weight distribution area of the first gray level at positions 15 to 30, is the black background. The other gray degree distribution weight areas at positions 75 to 90 represent the image representation of the phantom object that has the highest brightness.

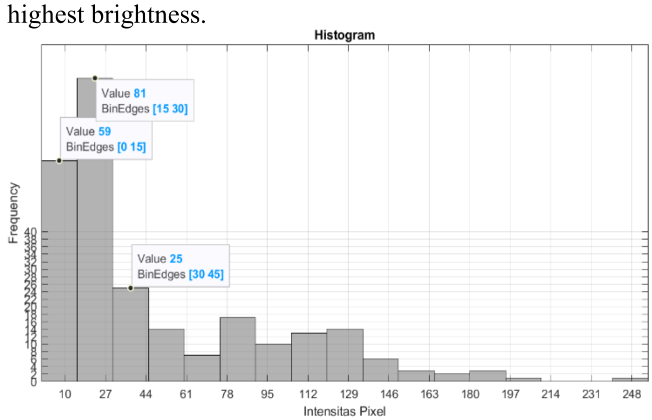


FIGURE 12 Histogram 2 Grey Level 55kV 20mA before Adjustment

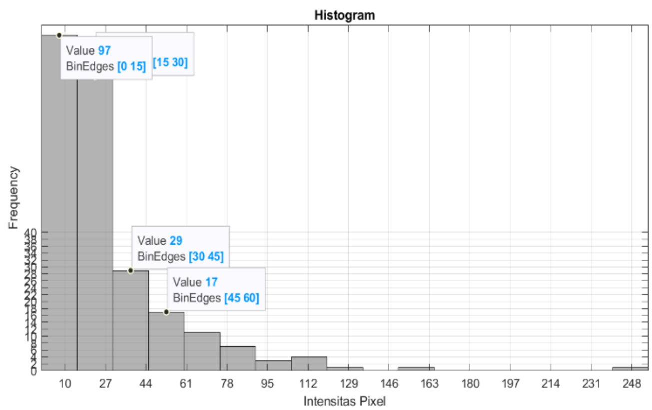


FIGURE 13 Histogram 3 Grey Level 60kV 20mA Before Adjustment

Histogram 3 shows the appearance of FIGURE 11(a), the blackish distribution of 0 to 30 which is the background of the image. Meanwhile, for the other degrees of gray, it is only 30 to 60 for object images.

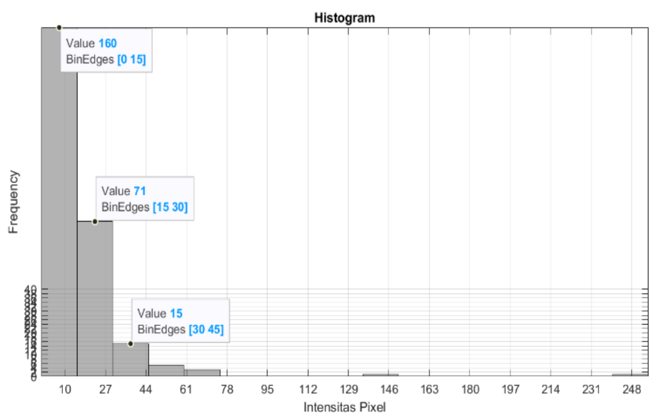


FIGURE 14 Histogram 4 Grey Level 70kV 20mA

Histogram 4 has a gray level distribution on the left so that it results in a very dark image display. Histogram 4 also has a dominant black color gradation. So that the contrast level of the image cannot be distinguished.

B. SENSOR HISTOGRAM ON MEASUREMENT OF KV AFTER ADJUSTMENT

By using the MATLAB application, the histogram is obtained as shown in FIGURES 17, 18, 19, and 20. Based on the type of actual distribution, the histogram tends to the left for all variations in the number of images, so the images tend to be dark.

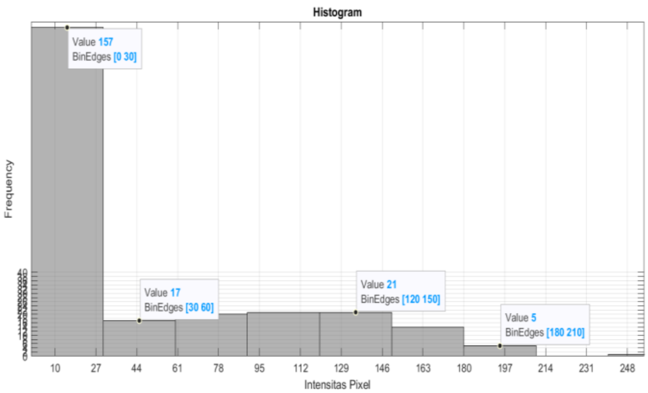


FIGURE 15 Histogram 5 Settings 50kV 20mA After Adjustment

Histogram 5 is a histogram that has been adjusted by subtracting object-resulted data from data without objects. With the adjustment of the distribution of the resulting data will be more even. A lot of data that does not need to be discarded.

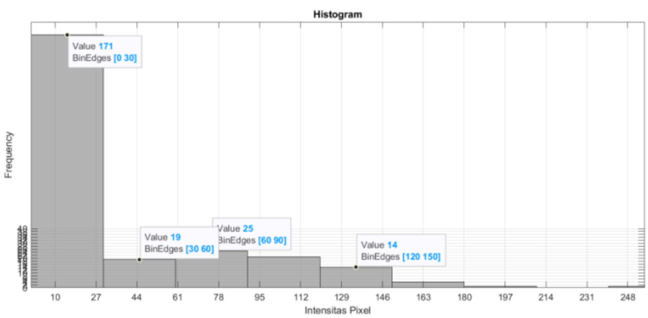


FIGURE 16 Histogram 6 Settings 55kV 20mA after Adjustment

Histogram 6 is the gray level of FIGURE 18. The first gray level distribution weight area at positions 10 to 30, is part of the black background. The weighted areas of the distribution of other gray degrees at positions 60 to 190 indicate image values that tend to be denser to black.

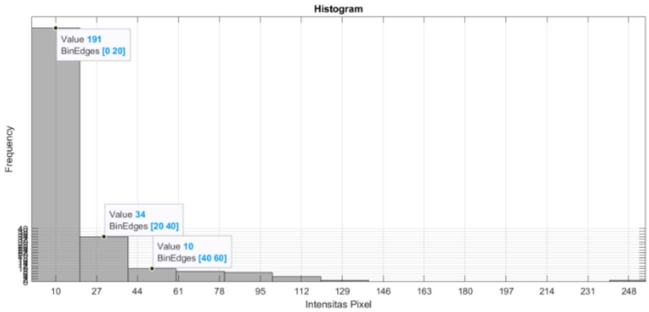


FIGURE 17 Histogram 7 Settings 60kV 20mA after Adjustment

Histogram 7 shows the appearance of FIGURE 19, the black distribution of 0 to 20 which is the background of the image. Meanwhile, for other gray degrees, it is only 60 to 129 for object images.

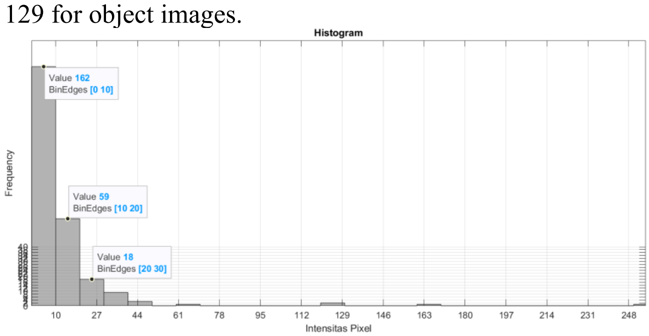


FIGURE 18 Histogram 8 Settings 70kV 20mA after Adjustment

Histogram 8 has a gray level distribution on the left, which results in a very dark image. Histogram 4 also has a dominant black gradation. So that the contrast level of the image cannot be distinguished

IV. CONCLUSION

The feasibility of an x-ray detector using a phototransistor has been previously verified by Ramacos Fadela making a kV detector design at changes in X-ray intensity which aims to determine the sensitivity of the phototransistor, a detector sensitivity of 0.037mV with an offset of 130mV is obtained. However, in this study the Darlington circuit is still used, namely an amplifier that combines 2 transistors, one of which is less affordable and difficult to find[18][19]. Based on this analysis, the authors conclude that the sensors used are often difficult to find and expensive. The diameter is also very large so the image quality is not good. In addition, a small field area will make the image less clear. Therefore, this study aims to design a flat panel detector using Phototransistor PH101 with kV setting parameters. Phototransistor PH101 sensor which has a diameter of 3mm smaller than Photodiode BPW34, it is hoped that the distance between adjacent sensors will improve image quality. Using a larger 16x16 matrix than previous research will clarify the image. Phototransistor PH101 is used to capture X-rays at an affordable price. Uses a different kV setting and is shown using MATLAB. Overall, this research concludes that a Flat Panel Detector Design Tool with Arduino-based Phototransistor PH101 Sensor has been made for the kV setting by utilizing different resistance results with different X-Ray intensities when connected to voltage division which can respond to the thickness of the object or without the object. Giving different kV settings with mA and s still affects the penetrating power which causes the catch to have different levels of gray on the object. After observing, experimenting and measuring data the authors conclude that the captured analog value has a range of 0-255 (8 bits). With a data distribution of 0-30 as background and 60-180 are objects. The uniformity value is obtained by finding the mode value on the exposure results without objects. Has a yield of 50kV with mode 20, 55kV with mode 16, 60kV with mode 13, and 70kV with mode 8. Object data equalization is done by subtracting object data with uniform data without objects. As a result, the resulting image becomes clearer. Image display at 50kV 20mA setting shows a relatively high image contrast that can be seen with parts of the object that can be distinguished from the background. The shape of the histogram before equalization looks more uneven with a large distribution of data. While the shape of the histogram after being equalized looks evenly distributed with less data distribution. The higher the kV value, the blacker the resulting image will be. Arduino Mega 2560 controls the device as a whole by using a voltage division circuit and a diode as a rectifier. From the results of research that has been done can be analyzed the lack of writing tools. The following suggestions for the development of this research can be carried out by displaying data in real time, speeding up the capture time to less than 1 second, replacing readings with a wireless system.

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