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Analysis of the Capture Output on Flat Panel Detector using Arduino-Based BPW34 Photodiode Sensor with mA and kV Setting Parameters

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ABSTRACT The exposure factor is the factor that determines the intensity and quality of X-rays received by the patient. Exposure factors that can be controlled are tube voltage (kV), tube current (mA), irradiation time (second), and distance of the X-ray tube to the film (FFD). The purpose of this study was to capture X-rays at a relatively affordable manufacturing price and to obtain different value from the detector's capture between dark and light by utilizing the response of the BPW34 photodiode sensor. The contribution of this study is that the system can display grayscale and numerical on an 8x8 pixel matrix using the Matrix Laboratory (MATLAB) Application. This study was able to convert images taken from analog data after taking measurements on X-rays. The measurements were carried out by 2 methods, the range used was 32-63 mA with a tube voltage of 50 kV at an irradiation duration of 1 second and 50 - 70 kV with a tube current of 40 mA and an irradiation duration of 1 second. Based on the measurement results, the comparison between the Flat Panel Detector Design Tool and the Philips brand Digital Radiography obtained that the latter was able to respond to differences in dose and object thickness. The results of this study indicated that this tool could be used to capture X-rays so that the degree of blackness of the film were obtained.

INDEX TERMS Exposure Factors, mA, kV, X-Rays, MATLAB, Photodiode BPW34

I. Introduction

Radiographic examination is an examination that utilizes X-rays to reveal the desired object through the making of a radiograph to obtain information that can support diagnosis [1][2][3]. Therefore, a proper setting for the exposure factor is needed to produce optimal radiograph quality. In this case, exposure factor is defined as the factor that determines the intensity and quality of X-rays received by the patient. Exposure factors can be controlled; these factors include tube voltage (kV) [4], tube current (mA) [5], irradiation time (second), and distance between the X-ray tube and the film (FFD) [6][7]. In this case, the tube voltage (kV) affects the main factor that controls the quality of X-rays, particularly its ability to penetrate the objects through which they pass. The tube voltage (kV) also affects the resulting radiograph contrast, characterized by the presence of blackish differences among several regions on the radiograph [8]. Many types of sensors can be used for light capture, for example LED and photodiodes [9][10][11][12][13]. However, the use of photodiodes to capture X-rays is still rare [14]. In this study, we tried to find out whether BPW34-type photodiodes could be used as X-ray detector [15][16]. Research that has been

conducted by Zhao in 1996 changed conventional film to detector tapes in the form of Flat Panel Detectors by using TFT as the detector to capture and convert them into visible light [17]. Furthermore, Yamamura in 2011 conducted a study using photodiode sensors arranged to produce a data matrix [18]. In 2014, Muhammad Irsal further examined the variations of exposure factors that affected doses administered to patients in medical imaging to reduce unnecessary exposure [19][20]. Another study was also carried out by Eduwin in 2021 using Matlab in the case of image processing segmentation [21]. In addition, Charles compared four commercial photodiodes as radiation detector for radiation dose measurement in 2016. This project revealed that BPW34 photodiode had the best response and sensitivity [22]. Furthermore, in 2017, Eif Sparzinanda discovered that the higher the tube voltage, the more the current and time given could reduce the contrast value, quantity, and brightness of the radiographic image [4]. Two years later, Matlab was utilized again in the research done by Atina, revealing that the tool certainly reduced the examiner analysis errors because the level of imagery grayness could be clearly described [24]. Additionally, Damulira in 2021

examined the differences between BPW34 photodiodes and LEDs as sensors for capturing X Rays, instead of as detectors for producing images [14][13][25][26]. Based on the problems and identification above, the author intended to use BPW34 photodiode sensor to capture X-rays in the Flat Panel Detector Design. This research aimed to make an FPD tool with a relatively affordable production price as an initial prototype which further had different value of the detector capture as a function of mAs between dark and light, which then converted the analog data to gray level and further could be developed into imagery. Furthermore, this article consists of 5 parts, where part II contains the methods and developments implemented, Part III contains the results obtained in this study, Part IV discusses the findings, and Part V provides a conclusion.

II. Materials and Methods

A. Data Collection

This study utilized a BPW34 photodiode sensor which was a diode that could detect light. This component converted the light into electric current. In this case, the types of light that could be detected by this photodiode included visible light, infrared light, ultraviolet light, and X-rays [14][24][27]. BPW34 is particularly a high speed photodiode commonly used in control and drive circuits. However, due to its short switching time (20nS), it can also be used for isolated data communication circuits and other long-distance communications, such as televisions, dimmers, and other equipment. Normally, the BPW34 is usually run-in series with the resistor, and the current that flows depend on the amount of light falling on it. In the current research, light intensity was measured in brightness. In addition, Arduino nano acted as the controller and reader, while its output was in the forms of a serial monitor [28][29]. BPW34 photodiode sensor used in the current project was employed to capture X-rays 3 times for each data collection at the settings of 32 mA, 40 mA, 50 mA, and 63 mA for 1 second with 50kV and the settings of 50kV, 55kV, 60kV, and 70kV for 1 second with 40mA. The value captured by the photodiode was further read by Arduino. After reading the data, Arduino changed the data from 10 bit into 8 bit and converted them into a data matrix, which were then stored in Microsoft Excel. MATLAB application was also utilized to convert the image into analog data. After the design was completed, a comparison test was carried out on the module and the comparator of the Phillips Digital Radiography to see the difference in the dosage and thickness of the object.

The following Figure 1 shows the Diagram Block and Flow Chart of the process. FIGURE 1 illustrates that when the detector was turned on, the battery gave voltage to the microcontroller but there was no data captured by the photodiode. When the radiographic plane gave an X-ray where part of the beam was absorbed by the object and the rest was passed to the screen to be converted into a visible beam, then it was captured by the photodiode and then processed by the microcontroller into a data matrix in 8 bit. After several images were captured, the results

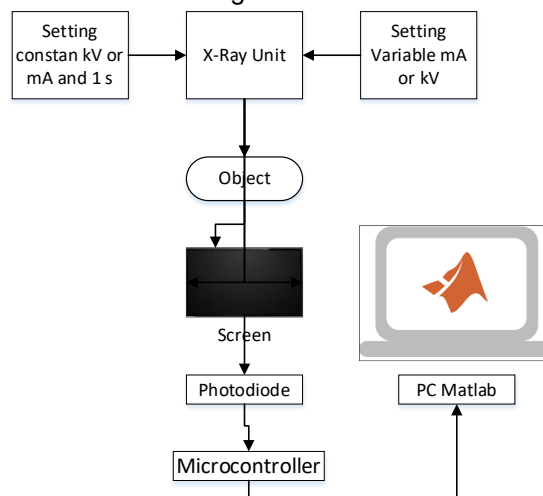were processed and displayed on the PC via a microcontroller using cable.

FIGURE 1. Block Diagram Processing data of Flat Panel Detector using photodiode sensors to display on Personal Computers
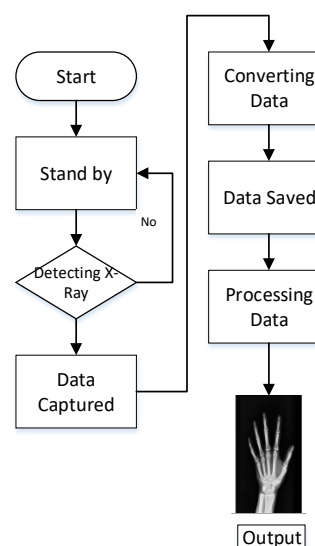

FIGURE 2. Flow Chart Processing data of Flat Panel Detector using photodiode sensor to display on Personal Computers

Based on the FIGURE 2 below, after the tool was connected to the PC using a cable, it entered a standby mode. In this case, it remained in the standby mode until it detected the X-ray. After the X-ray was detected, the data were captured by the detector, which further were processed and stored in Microsoft Excel. Furthermore, the data were sent to the MATLAB application to be processed in order to produce output in the form of images.

FIGURE 3 shows the System Mechanical Diagram, which is the system on the Arduino Photodiode-based Flat Panel Detector Replica. In this case, the data were received and then processed into an output image in JPG format that was displayed on the PC.

In this study, the Flat Panel Detector Design tool with the object was compared to the Phillips brand Digital Radiography tool in the Radiology laboratory of the

Campus of the Department of Electromedical Technology, Poltekkes Surabaya as shown in FIG. 4
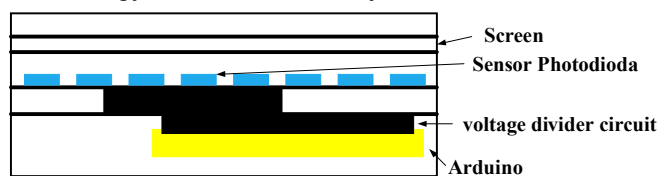

FIGURE 3. System Mechanical Diagram of Flat Panel Detector Arrangement using Photodiode sensor

FIGURE 4. Measurement with the Tool Compared

B. Data Analysis

Data analysis was carried out in two areas, those were the free area and the passage area. Current research involved 3 respondents who had 3 different weights (light, medium, and heavy). Data from each respondent were further collected 3 times for each area and command.

In this case, the average value is the number obtained from the result of the division of the number of data values by the amount of data in the set.

$$\text{Average } (X) = (\textstyle\sum Xi)/n \qquad (1)$$

Where X shows the average value of n measurements. N indicates the amount of data taken. Meanwhile, the number of data values is indicated by $\sum Xi$.

III.   Result

In this study, the Flat Panel Detector Design tool using object was compared to the Phillips brand Digital Radiography tool in the Radiology Laboratory of the Department of Electromedical Technology, Poltekkes Surabaya as shown in FIG. 5 and FIG. 6.

In Figure 5, the measurements between the standard tools and tools design was compared. In this case, the standard data compared used the Digital Radiography. The comparison was carried out on the image output on the computer display against digital radiography.

Figure 6 describes the placement of objects to see the difference in gray values in the Flat Panel Detector tool design. The gray value describes the power

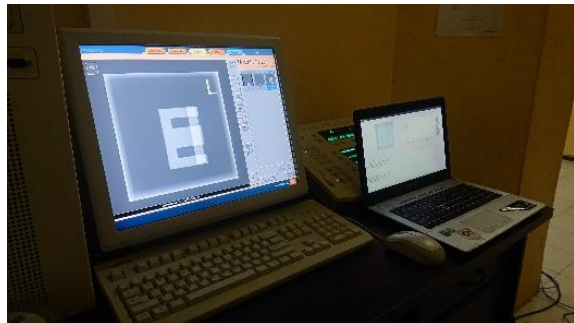captured on the flat panel detector which is then converted into an image with a degree of gray.

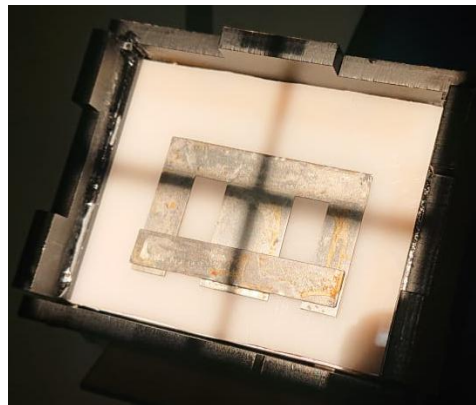**FIGURE 5.** Display of Measurement with the Tools Compared

FIGURE 6. The object placement to see the difference in gray values on the Flat Panel Detector Design tool
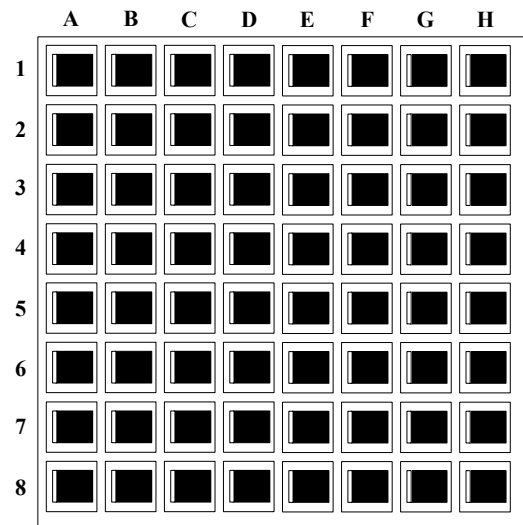

FIGURE 7. Ilustration of mapping 8x8 photodiode's

The first measurement of the data was conducted at the setting of 32 mA without using an object. The greyscale measurement done at the setting of 32 mA from three data collection without an object obtained an average value of 221.609 and a mode of 224. In this case, the results of the image (grayscale) obtained in the first analog data collection had a fairly bright light intensity as shown in FIGURE 8.

The second data measurement was carried out at the setting of 32 mA and 63 mA using object. The greyscale measurement at the setting of 32 mA from the three data

collection using the object obtained an average value of 230.92 and a mode of 234. In this case, the results of the image (grayscale) obtained in the first analog data collection had the ability to respond to a small penetrating power so that the color of the resulting object looked faint as shown in FIGURE 9.

FIGURE 8. Three Data Setting 32 Ma Without Object The Grayscale Have A Fairly Bright Light Intensity
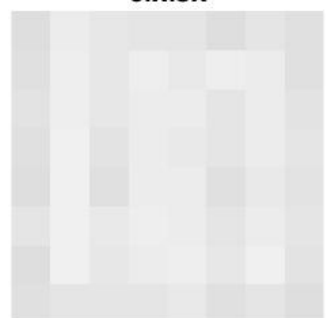

FIGURE 9. At the setting of 32 ma, the resulting image had a bright color. When the object was given voltage, the affected part had a lighter color but it stillcould not be clearly identified. Meanwhile, in parts that have different thicknesses the tool did not give any response.

The data measurement at the setting of 63 mA from the three data collection using the object obtained an average value of 218,54 and a mode of 226. In this case, the results of the image (grayscale) obtained in the first analog data collection had the ability to respond to a small penetrating power so that the color of the resulting object was brighter as shown in FIGURE 10.

FIGURE 10. At the setting of 63 Ma, the resulting image had a dark gray color. Objects were identified well and the difference in thickness could be seen well.

Based on the data measurement at the mA setting using an object and without an object, there was differences. At the setting of mA without an object, the color of the resulting object was not very visible compared to the data collected at the setting of mA using object.

Meanwhile, the mA setting that used object had a black density difference between the 32 mA setting and the 63 mA setting.

After observing the results of the data obtained, the mA setting affected the intensity of the gray produced by this tool, where the greater the mA, the more the amount of data received by the tool will be evenly distributed and resulted a uniformed gray level in the entire area. In addition, the greater the mA setting, the greater the gray concentration of the resulting image and the more visible the difference between the object and the part that is not exposed to the object. Furthermore, in order to determine the whether sensor's ability in capturing X-rays is good or not, then a graph was made from the setting of 63 mA 50 kV which was known to have an average value of 199 [30].

Furthermore, the next data measurment at the setting of 70 kV without object was carried out. Figure 11 shows the result of the measurement data drawing on the setting of 70 kV of the third data captured without objects. This third data collection table had an average value of 207.516 and a mode value of 211. The resulting image (gray scale) in the first analog data capture had a dense light intensity.

FIGURE 11. Third Data Capture Image Results without Objects at the setting of 70 kV

The next data measurement was done at the setting of 50 kV and 70 kV using object. Figure 12 shows the data measurement at the setting of 50 kV of the first data collection using object. The first data collection table of kV measurement results at the setting of 50 kV had an average value of 238.75 and a mode value of 233. In this case, the resulting image (grayscale) obtained in the first analog data collection had the ability to respond a small penetrating power so that the color of the resulting object was brighter.

FIGURE 12. The Result of the First Data Capture Image using Object at the Setting of 50 Kv

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FIGURE 13. Third Data Capture Image Results using Objects at the Setting of 70 kV

FIGURE 13 is the data measurement at the setting of 70 kV for the third data collection using object. The third data collection table of kV measurement results at the setting of 70 kV obtained an has an average value of 216.125 and a mode value of 220. In this case, the resulting image (gray scale) obtained in the first analog data collection had the ability to respond to high penetrating power so that the color of the resulting object was darker.

Based on the data measurement as presented in Figure 11, Figure 12, and Figure 13 of setting kV using objects and without using objects, it can be seen that in the kV setting without objects, the color of the resulting object was not very visible compared to data collection using objects. Meanwhile, in terms of the setting of kV using objects, there was a difference in the level of blackness density between the setting of 50 kV and the setting of 70 kV[29], [31].

After observing the results of the data that have been obtained in several kV settings, it affected the grayness intensity produced by this tool, which was the greater the kV, the brighter the luminescence produced by the screen and captured by photodiodes. The larger the kV setting, the darker the resulting image and the more visible the difference between the object and the part that is not exposed to the object.

Furthermore, data measurment was also carried out at the setting of 32 mA, 40 mA, 50 mA, and 63 mA without object. The measurement results of the Flat Panel Detector Design Tool with settings of 32 mA, 40 mA, 50 mA and 63 mA had a small difference from each data taken. Therefore, the level of precision of the sensor on the Flat Panel Detector Design Tool was quite precise to receive X-rays at the same level. When giving objects with different thicknesses, the Flat Panel Detector Design Tool showed the results of the response to the difference in thickness by showing the difference in the resulting gray color [28][31]. It is shown in FIGURE 14.

Data measurment was additionally conducted at the setting of 50 kV, 55 kV, 60 kV, and 70 kV without object. After observing the results of the data that have been obtained, the kV setting had an influence on the grayness intensity produced by this tool, which was the greater the kV, the brighter the luminescence produced by the screen rand captured by the photodiode. In

addition, the larger the kV setting, the darker the resulting image and the more visible, the difference between the object and the part that was not exposed to the object [28][31]. It is presented in FIGURE 15.
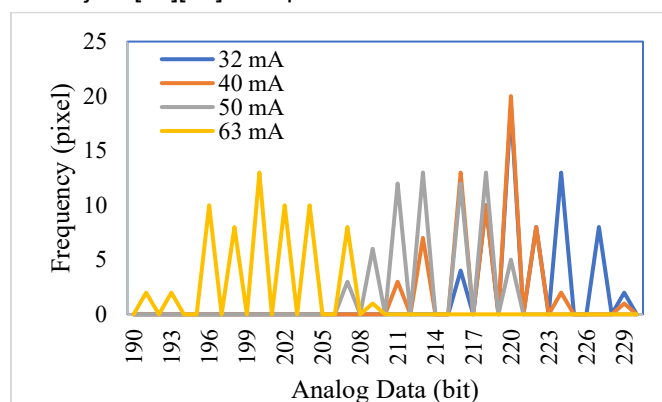

FIGURE 14. Data Measurment at the Setting of 32 mA, 40 mA, 50 mA, and 63 mA without using object
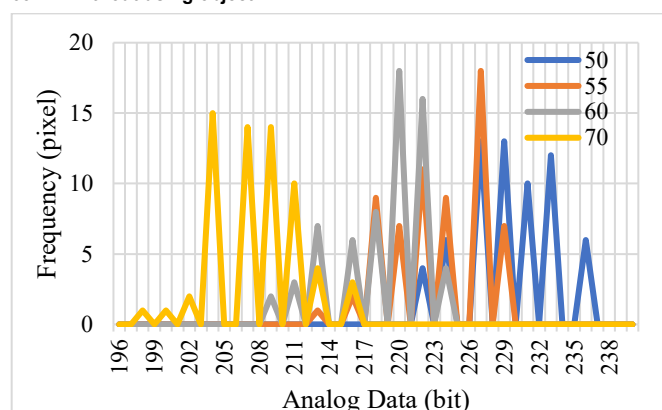

FIGURE 15. Data Measurment at the Setting of 50 kV, 55 kV, 60 kV, and 70 kV without using object

Data Comparison of Flat Panel Detector Design With Arduino-Based BPW34 against mA and kV Settings. This process was done by utilizing different resistance results with different X-ray intensities as well as connection to voltage division which can respond to the thickness of objects and without objects. The provision of different mA, kV, and s settings affected the density of the grayness level in the entire area either it used object or not. Meanwhile, the provision of kV settings that are different from mA and s affected the penetrating power which further caused the different grayness level on the object.

Data Comparison between the Digital Radiography (DR) and Flat Panel Detector Design Tool. Figure 16 to 19 shows the comparison between the Digital Radiography (DR) images and the Flat Panel Detector Tool using the setting of 70 kV 40 mA 200 ms and 70 kV 40 mA 1 s [1][32][33][34].

Furthermore, when it was compared to the Phillips Digital Radiography, this tool had a weakness in the response time of capturing images. When given an exposure time of 200 ms, the image on the Phillips Digital Radiography brand had a good image, yet when the exposure time finished, the tool could not process all

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the data so that it affected the results of the unfinished image. When the exposure time of 1 second was given, the results obtained a complete image, but the image of the Phillips Digital Radiography brand was not visible because it took too long to receive a dose leading to too much data read [35].

The cause of the tool inability to read all data at the 200 ms time setting occurred due to the alternating reading process which still required a relatively long time.

FIGURE 16. Digital Radiography (DR) Image Results at the Setting of 70 kV 40 mA 200 ms had a good image.

FIGURE 17. Digital Radiography (DR) Image Results at the Setting of 70 kV 40 mA 1 second resulted in the image that was not visible because it took too long to receive a dose, leading to too much data read.

200ms.xlsx

FIGURE 18. Image Result of Flat Panel Detector Tool at the Setting of 70 kV 40 mA 200 ms could not process all the data so that it affected the results of the unfinished image.
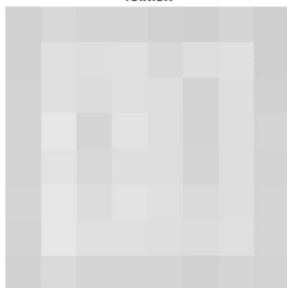
1s.xlsx

FIGURE 19. Image Result for Flat Panel Detector Tool at the setting of 70 kV 40 mA 1 second displayed a complete image.

In the case of data comparison between the Digital Radiography (DR) and the Flat Panel Detector Design Tool, the Flat Panel Detector Tool Design was displayed through the MATLAB application. This data was in the form of analog data that stored in Microsoft excel and

then displayed in the Matlab application. After the excel file was selected and then opened in the MATLAB application, the application converted the data into an image. The resulting data was further saved in jpg format.

In FIGURE 20, there was a box (left side) used to display an image of the converted analog data. Meanwhile, the histogram graph (right side) was employed to see the blackish change and obtained the mode value. "Open xls File" button was used to open the saved excel file from the Design Tool. Then the "Save Images" button was utilized to save the image and histogram results from the data that had been taken.
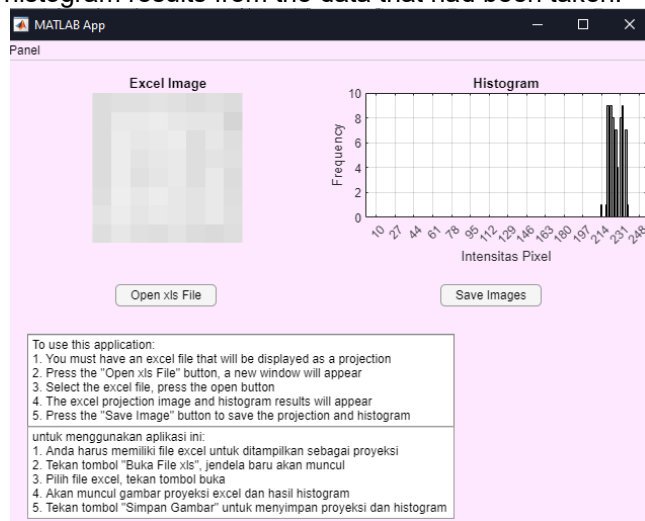

FIGURE 20. Display of MATLAB APP DESIGNER

IV. Discussion

After observing the results of the data obtained, the settings of mA and kV affected the gray intensity produced by this tool. In this case, the greater the mA, the more evenly distributed the amount of data received by the tool and the results at the gray level in the entire area become uniform. The greater the mA setting, the greater the gray concentration of the resulting image and the more visible the difference between the object and the part that was not exposed to the object. The larger the kV, the brighter the light produced by the screen and captured by the photodiode. In addition, the higher the kV setting, the darker the resulting image and the more noticeable the difference between the object and the unaffected part [28][31].

Digital Radiography (DR) issued X-rays which further were captured by the Flat Panel Detector Design module. The X-ray device then passed through the screen that emitted light and captured by the photodiode [14][24][27]. The data that had been captured by the photodiode were then forwarded to a voltage division circuit connected to the microcontroller, the greater the X-rays given, the greater the voltage flowed to the microcontroller. The results of this study displayed data in the form of images generated by X-rays, where the data processing utilized MATLAB application [23][24]. The design of this research is as an initial design of an X-ray detector based on a photodiode sensor which is relatively affordable in its

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manufacture. The drawback of this Flat Panel Detector design is that the detected response time should not be less than 1 second. The cause of the tool inability to read all the data at the setting of 200 ms time occurred because the process of reading back and forth which still took a relatively long time. For further research it is necessary to add pixels in order to produce a better image and display data in real time [4].

V.   Conclusion

This research aims to determine whether the BPW34 photodiode can be used as a replacement for the usual flat panel detector when different mA settings are given. At the 63 mA setting, the resulting image has a dark gray color. Objects can also be identified well and the difference in thickness can be seen well. In addition, when different kV settings are given, particularly at the setting of 70 kV, we can see the darker area and lighter area in shape of the object. Therefore the current research can be applied in capturing X-rays with relatively affordable manufacturing costs as an initial prototype that can be developed into an image. This research is built based on Arduino Nano, BPW34 photodiode sensor, and MATLAB application. After doing a comparison using the Digital Radiography Phillips brand, this Flat Panel Detector Design Tool is able to respond to differences in dosage and thickness of objects. Further research on the Flat Panel Detector Design Tool needs to be done in order to correct its shortcomings, namely the detected response time should not be less than 1 second. In addition, it is necessary to add pixels in order to produce better images and data display in real time.

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