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Experimental Measurement and Analysis: Collimation and Illumination for Conformity Measuring Instrument Design in X-ray Modality

Fathul Fajar[1], Muhammad Ridha Mak'ruf[1], Andjar Pudji[1], and Achmad Rizal[2]

[1] Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, Surabaya, Indonesia
[2] School of Electrical Engineering, Telkom University, Bandung, Indonesia

Corresponding author Muhammad Ridha Mak'ruf (email: ridha@poltekkesdepkes-sby.ac.id)

ABSTRACT Manual illumination and collimation testing can be affected by subjectivity. Human interpretation and judgment in measuring and adjusting illumination and collimation can vary between individuals, potentially resulting in inconsistent results. The aim of this research is to develop the simplest method for measuring illumination at four points simultaneously and directly storing the measurement data. This objective aims to address the subjectivity issues and improve the reliability and consistency of the testing process, which measures illumination at four points simultaneously and stores the measurement data directly. The method of this study was an experimental measurement and analysis that involved capturing illumination and collimation data using a suitable measuring instrument in an X-ray environment. The collected data is then analyzed to evaluate the suitability of the instrument to the established compliance standards. The module is designed using HC-SR04 sensor as a distance meter and TSL2561 sensor as a light meter. This module is designed using HC-SR04 sensor as a distance meter and TSL2561 sensor as a light meter. In this research, the module has been tested and compared with the results of the comparison tool (Digital Light Meter) and obtained an error value of 1.55% with a module efficiency of 98.45% in the illumination test, and an error of 1.8% with a module efficiency of 98.2% in the collimator test. From this research, it can be concluded that the TSL2561 light sensor can be used to measure the illumination area of the collimator lamp. The contribution of this research is expected to be as follows consistent results from tool testing, provides accuracy of results, is more efficient in cost and energy, and the data will be stored until the next testing time.

INDEX TERMS experimental measurement and analysis, TSL2561, HC-SR04, Lux. the illumination and collimation test

I. INTRODUCTION

The X-ray machine is one of the most useful medical equipment today by utilizing a tube as a source and using the parameters Kv and mA[1]–[6]. In radiology equipment, there is a conformity test, where the conformity test is a test of the function or performance of the tool [7]–[9]. Each radiology or X-ray device is required to perform a functional or performance test of an X-ray modality in accordance with the radiation safety standards of the International Atomic Energy Agency (IAEA). The suitability test has several parameters and parts. In the X-ray modality Suitability Test, there are X-ray beam collimation tests, X-ray generators and tubes, and AEC. Collimation Test X-ray beam contains illumination where light from the collimator lamp must be well visible in order for the area of the irradiated field to be correctly identified.. The collimation field difference with the X-ray beam is where this is intended for patient safety and the accuracy of the X-ray machine. The beam perpendicularity where this test is intended to measure the perpendicularity of the X-ray beam so that the quality of the X-ray image results is accurate and precise.[10]–[13]. The suitability test is also to maintain patient safety from the dangers of an excess dose of

X-ray radiation which will affect the patient's health [14]–[16]. The process of testing x-ray equipment itself has been listed in BAPETEN Decree No. 2 of 2018 where there are requirements and standards for testing tools. In order to improve radiation safety for patients, radiation workers, and the general public, the screening process for diagnostic and interventional radiology X-rays needs to be optimized to keep pace with the times and technology [17].

L. R. Bridge and J. E. Ison conducted an illumination test survey on some patient data to determine the value of illumination efficiency, then obtained the average value of measurements for stationary X-ray is 123 lux and mobile X-ray is 141 lux in 1995 [18]. M. Begum performed a quality control test on an X-ray machine using a beam alignment tester to measure focal spot area, screen contact, and HVL in 2011.[19]. In 2010, C. C. Nzotta and C. Anyanwu stated that the collimation and illumination parameters are parameters that need to be checked periodically because the mismatch of collimator lamp light to X-ray beams can be affected by the amount of deviation of the X-ray beam, and the minimum standard illumination value is ≥100 lux [20]. In 2017, A. S. Moi et al., carried out a conformity test for collimation measurements on a thorax examination and the results were poor, therefore it was still necessary to optimize the Conformity Test. To measure illumination, you need a Lux meter [21]. Karel Sokanský and Petr Závada made discussion of a long-term instrument for light data collected under the night sky and comparison of light levels [22]. Jawaaz Ahmad, Romana Yousuf use LDR as sensor on Lux Meter [23]. Roman Hrbac built a lux meter for dimmable lighting spread on trains to limit maximum energy consumption [24]. Al-haija, Qasem Abu designed a lux meter using ARM Cortex M4 with TM4C123 microcontroller [25].

Based on the literature above, all conformity tests carried out are based on BAPETEN regulations where one of the parameters of this conformity test requires a tool which until now is still a lot of people using an ordinary tool which still has a lot of risks, for example, reading errors on each person. Which uses (human error), different levels of parallelism and perpendicularity due to the unknown value of the flatness between the tube and the patient table. It is therefore the author's goal to Collimation and Illumination Analysis of Conformity Measuring Instrument Design in X- Ray Modality.

The aim of this research is to develop the simplest method, which measures illumination at four points simultaneously and stores the measurement data directly. The contribution of this research is to provide information on X-ray modality measurements at both points with known and stored results. Furthermore, it allows the development of a conformity testing format that facilitates and minimizes human errors, as well as the development of the simplest method. Additionally, it enables the capability to measure illumination at four points simultaneously and directly store the measurement data.

II. MATERIALS AND METHODS

A. RESEARCH DESIGN

This study uses a light sensor TSL2560 to measure lux and HCSR04 to measure distance, then the data will be sent via Bluetooth to a PC to display and save the measurement results in Microsoft Excel. Data retrieval is carried out on a radiology plane with the method of collecting data for the illumination test and ui collimation.

B. MATERIALS AND TOOLS

This study uses four light sensors TSL2561 and a proximity sensor HCSR04. The output of this sensor will then be processed in the Arduino Mega, then the sensor will be given a digital filter for smoothing. Arduino output will be displayed on the LCD and Delphi.

C. EXPERIMENT

In this study, after the tool module has been completed, a comparison test will be carried out on the module and comparison to see the difference in illumination measurements in the four collimator areas, the distance on the x-ray tube and bucky table, and the collimation results.

D. BLOCK DIAGRAM

FIGURE 1 shows The system starts to work when the appliance is turned on. The microcontroller initializes the connected hardware including the LCD, Bluetooth module, HC-SR04 proximity sensor, and TSL2561 sensor. The HC-SR04 proximity sensor measures the distance or height of the collimator focus to the bucky table (SID) and the TSL2561 sensor measures the light intensity in lux units. The microcontroller processes the sensor readings, which are transmitted via Bluetooth so that they can be displayed by the PC and also displayed on the LCD. The results of the proximity sensor and light sensor readings are stored on a PC, so that the measurement results carried out can be viewed again if required one day.

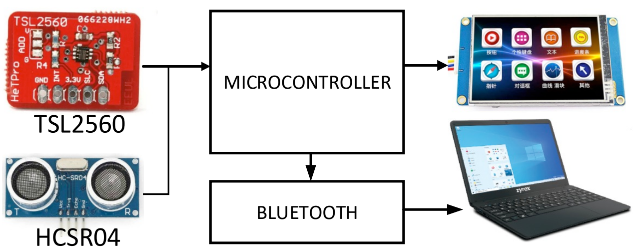

FIGURE 1. Block diagram contains input, process, and output blocks

E. FLOWCHART

In FIGURE 2, when the start or the tool is on, the tool initializes. Then the sensors work. The HC-SR04 performs a SID distance reading. If it does not reach 100cm then the tool will read again. If YES, then the TSL2561 sensor will measure the light of the collimator lamp. Then all the data obtained is displayed via the LCD and transmitted by Bluetooth to be displayed and stored on the PC.

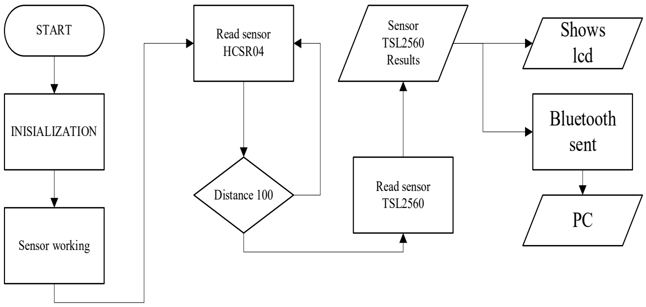

FIGURE 2. Flowchart containing the tool workflow from the tool on to completion.

F. DATA COLLECTION

Test method according to [26]. The illumination level of the collimator lamp should not be less than 100 lux at the focal distance – film 100 cm. Measuring instrument: light meter / illumination meter with collimation fully open, turn on the collimator lamp. Measurement of illumination on an X-ray plane by placing a Lux meter 100 cm from the X-ray tube. Make sure the Lux meter is parallel to the axes of the anode and cathode. Turn on the collimator lamp and measure the level of illumination by dividing the four areas (each measured alternately) and the collimating field area of 25x20 cm. Next, evaluate the collimator lighting level. The value passed the test >= 100 lux.

The Collimator Light Beam Similarity Test Method (Collimation Test) in the Quality Control and Conformity Test activities as described in [26], to determine the accuracy of the similarity between the X-ray beam and the light beam and to evaluate the accuracy of the X-ray beam to the center of the beam. Place the 25 x 20 cm cassette on a flat surface. Ensure that the anode and cathode axes are parallel to the cassette. Centre the X-ray tube in the center of the cassette and set the distance between the focus and the film (SID) to 100 cm. Place the collimator test tool in the center of the cassette. The collimator light is aligned within the rectangular area of the test tool plate. Place the beam alignment test tool in the center of the illumination area. Switch on the collimator light and adjust the area of the light field according to the rectangular line on the surface of the plate. Expose to obtain an optical density on the film that can be observed by the evaluator. Process the film in the darkroom and check the suitability of the X-ray beam and beam alignment. Repeat for other spot sizes.

G. DATA ANALYSIS

Measurement was carried out on a General X-ray machine for 5 measurements. The illumination measurement on the collimator lamp will be compared with a calibrated Lux Meter and the height/distance parameter measurement will be compared with the meter.

The average is the number obtained from the result of dividing the number of data values by the number of data in the set. The formula for the average is (Eq. 1):

$$(X) = \frac{X1+X2+\cdots+Xn}{n} \quad (1)$$

where X is the average, then X1, …, Xn is the data value and n is the number of data (1,2,3,………,n). Error (error) is the difference between the mean of each data. Error formula is:

$$ERROR\ \% = \frac{Data\ Setting - mean}{Data\ Setting} \text{ x } 100\% \quad (2)$$

The measurement of the value of passing the illumination test is the calculation of the measurement of each data obtained using a lux meter and analyzed, compare it with the data passed the test where the test result data must ≥ 100 Lux using the following formula (Eq. 3):

Illumination = average rated lux – background lux (3)

Then analyze the data on testing the collimation area of the x-ray beam by calculating the difference between the collimation field and the X-ray beam field (Δ) based on the difference in the position/value of X1, X2, Y1 and Y2. Then then compare it with the value passed the test where x and y 2% SID (Eq. 4 and Eq. 5).:

$$\Delta X\ (\%SID) = \frac{|X1|+|X2|}{SID} \times 100\% \quad (4)$$

$$\Delta Y\ (\%SID) = \frac{|Y1|+|Y2|}{SID} \times 100\% \quad (5)$$

III. RESULTS

From the research that has been done by the researcher, a result has been recorded. TABLE 1 and FIGURE 3 are the results of the illumination measurements with four collimator areas. TABLE 2 and FIGURE 4 are the result of testing the distance sensor HCSR04, is used to read the distance between the collimator (focal point) and the bucky table, readings are carried out on an x-ray plane before testing the lux value and measuring the difference in the area of the irradiating field.

TABLE 1.
Illumination measurement result Measurements were made by comparing the module with the Digital Light Meter Model 5202 KYORITSU ELECTRICAL INSTRUMENTS WORKS, LTD.

Measurement Point	Comparative Results	Module Results	Percentage
1	190	186	2.1%
2	189	187	1.0%
3	186	189	1.5%
4	188	185	1.6%
Error			**1.55%**
Module Efficiency			**98.45%**

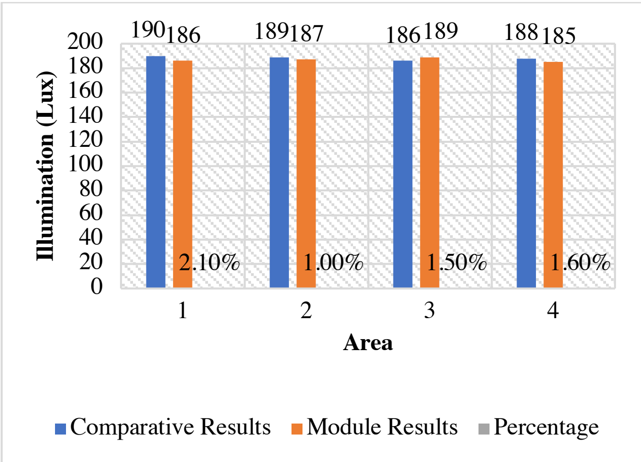

FIGURE 3. Chart contains of the Illumination measurement result Measurements were made by comparing the module with the Digital Light Meter Model 5202 KYORITSU ELECTRICAL INSTRUMENTS WORKS, LTD.

TABLE 2.
Distance measurement results which include the data module, comparison and error value.

Measurement	Comparison (cm)	Module (cm)	Error (%)
1	100	100	0
2	100	101	1
3	100	100	0
4	100	99	1
5	100	99	1

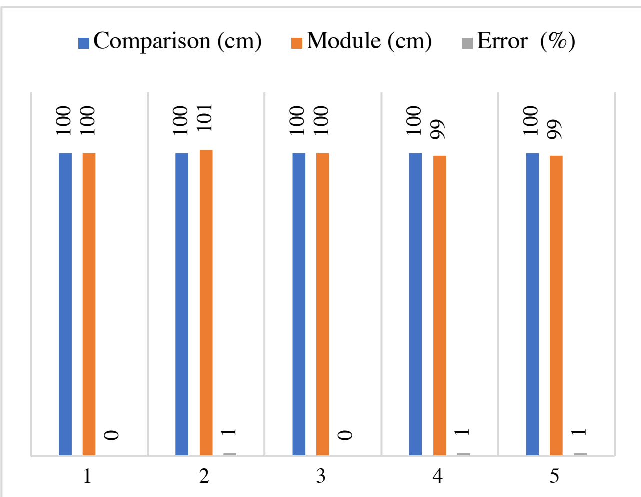

FIGURE 4. Chart contains of distance measurement results which include the data module, comparison and error value.

TABLE 3 and FIGURE 5 are measurement data from 4 measuring points from the module and comparison tool. The percentage value at measuring point 1 is 0.0%, measuring point 2 is 2.8%, measuring point 3 is 3.6% and at measuring point 4 is 1.1%. The module efficiency of these results is 1.8%.

TABLE 3.
Module results to the results of x-ray images perpendicular conditions

Measuring Point	Edge Light Field module (cm)	Comparative Results (cm)	Percentage
X1	7	7	0,0%
X2	7	7,2	2,8%
Y1	9	8,6	3,6%
Y2	9	8,9	1,1%
	Errors		1,8%
	Module efficiency		98,2%

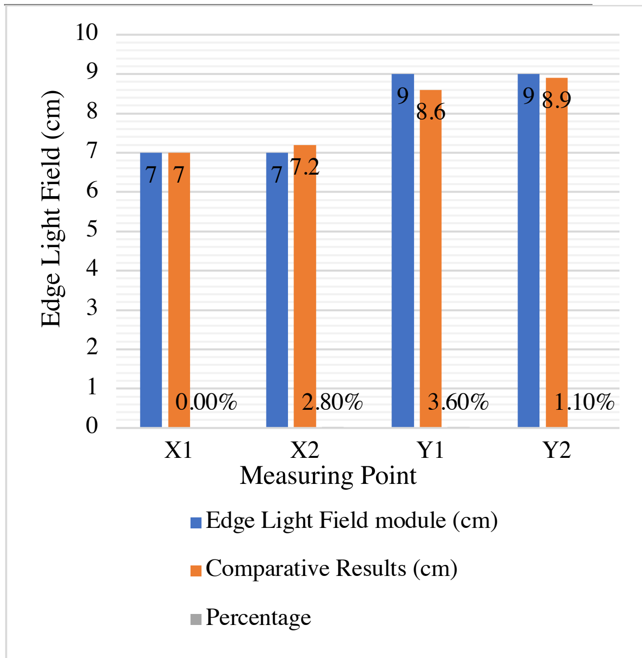

FIGURE 5. Chart contains of module results to the results of x-ray images perpendicular conditions.

From TABLE 4 and FIGURE 6 it can be seen that the results of testing the illumination of the collimator lamp on an x-ray radiography machine on two different tools in 4 areas of the irradiation field. On the Philips brand radiography device, the value is 188 lux with a backlight of 35 lux so that the test result value is 153. On the Philips brand radiography, the value is 202 lux with a backlight of 35 lux so that the test result value is 167. So the difference between the backlight and collimation light greater than 100 lux.

TABLE 4.
X-ray modality collimator light Illumination Test Results by comparing overall average with light room

Light Room (Lux)	Measuring instrument	Area	Mean (Lux)	Overall average (lux)	Test results	Test Pass Score
	Modul	I	188	188	153	>100 lux
		II	189			
		III	189			

		IV	186			
35	Eco view	I	202	202	167	
		II	202			
		III	203			
		IV	203			

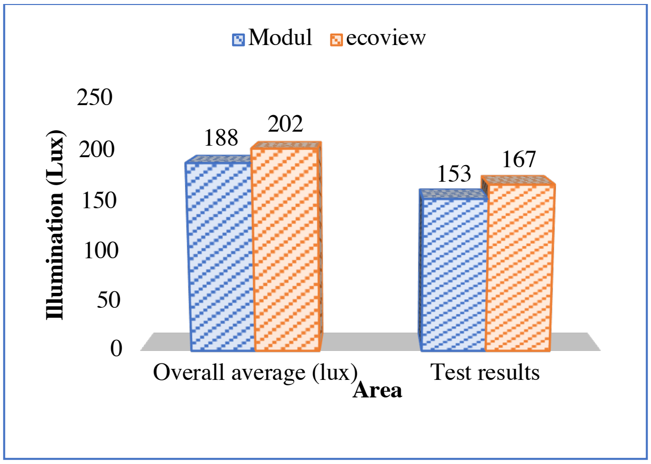

FIGURE 6. Chart contains of x-ray modality collimator light Illumination test results by comparing overall average with light room measurements.

TABLE 5 and FIGURE 7 are the measurement of collimation test data on an x-ray machine. Taken according to the X-ray beam collimation test data collection method.

TABLE 5.
Results of the collimation field difference test with x-ray beams

Tool's name	Measurement points	$\|\Delta 1\| + \|\Delta 2\|$ (% SID)	$\Delta X + \Delta Y$ (% SID	Test pass score
phillips	ΔX	0,142	0,317	ΔX and $\Delta Y \leq 2\%$ SID $\|\Delta X\|+\|\Delta Y\| \leq 3\%$ SID
	ΔY	0,175		
Ecoview Ultra 200	ΔX	0.138	0.322	
	ΔY	0.184		

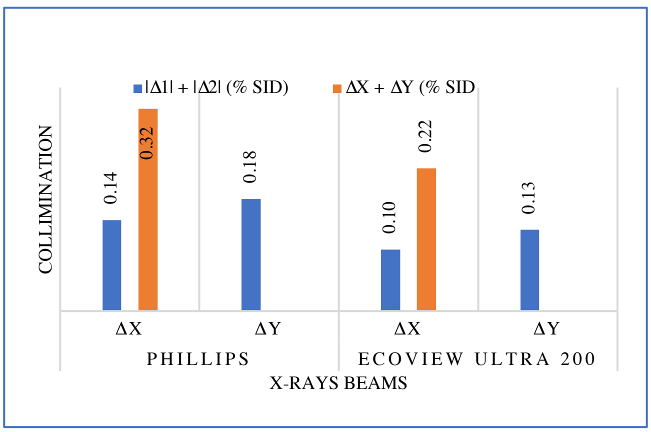

FIGURE 7. Results of the collimation field difference test with X-Ray Beams.

FIGURE 8 is an image that is the result of measuring the Philips X-ray equipment through conformity test activities in accordance with the data collection procedure.

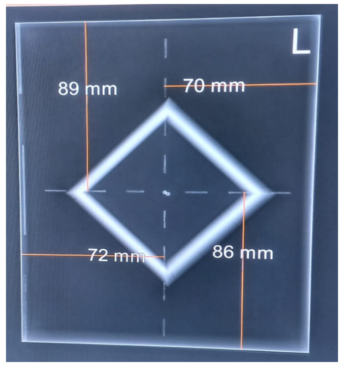

FIGURE 8. Results of the collimation test on a phillips x-ray machine, the value of the light lap for x1 is 7 cm, x2 is 7 cm, y1 is 9 cm, and y2 is 9 cm. Then for the value of the x-ray lap, x1 is obtained 7cm, for x2 7.2 cm, for y1 8.6 cm, for y2 8.9 cm.

FIGURE 9 is an image that is the result of measuring the Ecoview Ultra 200 x-ray equipment through conformity test activities in accordance with the data collection procedure

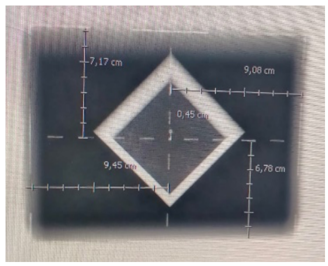

FIGURE 9. Collimation test results on the ecoview ultra 200 x-ray machine, the value of the light lap for x1 is 7 cm, x2 is 7 cm, y1 is 9 cm, and y2 is 9 cm. Then the x-ray values are obtained for x1 6.7 cm, x2 values are 7.1 cm, y1 values 9.4 cm, and y2 values 9.08 cm.

IV. DISCUSSION

Add similar paragraph comparisons from this sentences Based on the illumination test of the collimator lamp with 4 irradiation areas, the results are shown in TABLE 1 and TABLE 4. Where the value is 188 lux and the test results are 153 lux, which is the difference between the backlight and the collimator light, which is worth more than 100 lux, on a Phillip X-ray plane. Then the value of 202 lux is obtained and the test results are 167 lux where the difference between the backlight and collimator light is worth more than 100 lux. There is an X-ray plane with the Ecoview Ultra 200 brand. an average error of 1.55% with an efficiency value of 98.45%.

Tests and measurements of collimation field differences with X-rays are carried out using a manufactured module. The measurement method is performed by adjusting the X and Y axes between the X-ray field and the visible light field. After testing with the Beam Alignment Test Tool, the data shown in TABLE 3 and TABLE 5 were obtained. Based on the measurement results of the X-ray modality suitability test, an average error of 1.8% was obtained, with an efficiency value of 98.2%. A special module is used to measure the distance between the collimator (focal spot) and the bucky table. The measurement method is done by placing the module or tool that has been made in the middle of the collimator (Focal Spot) with the Bucky Table compared to the meter. After measuring, the data obtained as in TABLE 2. The minimum error value is 0% and the maximum value is 1%.

Based on the information provided, there are several limitations in the current research that can be identified as follow. The tool being used in the research has a relatively large size, which can be cumbersome and take up significant space. This could limit its portability and practicality for certain applications, especially in environments with limited space. The sensor being used in the research has a large range. While a large range may offer some advantages in certain scenarios, it might not be necessary for the specific purpose of the X-ray modality suitability test. A sensor with a smaller range could potentially be more suitable for this application, as it may provide more precise and targeted measurements. The current setup relies on a laptop as an additional tool to save the test data results. This laptop dependency can create issues related to portability and convenience, as well as potentially introduce compatibility concerns with different operating systems or hardware configurations. The results of the data collected by the sensor are still in the form of raw measurement numbers. These raw measurements have not yet been processed into meaningful results for the X-ray modality suitability test. This limits the immediate usability of the data and requires additional processing and analysis, which may be time-consuming and complex.

Therefore to address these limitations, several improvements can be considered. The tool's design can be revised to make it more compact and portable. This would make it easier to handle and use in various settings, including environments with limited space. Selecting a sensor with a smaller, more appropriate range for the X-ray modality suitability test can improve precision and accuracy in measurements. This may also help in reducing the size and weight of the overall tool. To eliminate the need for a laptop, the tool could be equipped with built-in data storage capabilities. This would allow it to store test data locally, enabling researchers to access the results without the need for additional devices. Rather than providing raw data output, the tool could be enhanced to process the measurements and present the results of the X-ray modality suitability test directly. This would provide more immediate insights and facilitate decision-making. By making these improvements, the research tool would become more user-friendly, practical, and efficient, leading to enhanced usability and accuracy in conducting X-ray modality suitability tests.

V. CONCLUSION

The purpose of this study is to highlight the findings and applications of using the TSL2561 light sensor and HC-SR04 proximity sensor for assessing the performance of the collimator lamp and determining the height between the collimator and the bucky table in an X-ray machine. Based on the planning, module manufacturing, writing, and data analysis, it is evident that the TSL2561 light sensor can be used to measure the illumination (light intensity) in the collimator lamp irradiation area of the X-ray machine. The irradiation area is specified to have a size of 25x25cm and is divided into four distinct areas: I, II, III, and IV. The TSL2561 light sensor is a suitable choice for this purpose as it is capable of accurately measuring light intensity. By placing the sensor in each of the four areas (I, II, III, and IV), the illumination levels can be measured separately to determine the condition of the collimator lamp.

The data obtained from the TSL2561 light sensor can provide valuable insights into the uniformity and intensity of light in each area. By analyzing the data, it is possible to identify any discrepancies or irregularities in the collimator lamp's performance, such as uneven illumination or a decrease in light intensity, which could indicate a need for maintenance or replacement of the lamp. In conclusion, the use of the TSL2561 light sensor for measuring illumination in the collimator lamp irradiation area can help in assessing the condition of the lamp and ensuring proper functionality of the X-ray machine. This data-driven approach can lead to more effective maintenance strategies and enhance the overall performance and safety of the X-ray equipment.

The HC-SR04 proximity sensor can be used to determine the height between the collimator (focal spot) and the bucky table. Collimator test tools can be made of acrylic to measure the accuracy of X-ray beam collimation in collimator tests. The result of measuring the distance/height between the collimator and the bucky table compared to the gauge on the X-ray unit has a minimum error value of 0% and a maximum error value of 1%. The results of the measurement of the illumination of the collimator lamp in each irradiation area between the design of the Lux Meter and Lux Meter which are calibrated with the result value of the Digital Light Meter comparison tool Model 5202 KYORITSU ELECTRICAL INSTRUMENTS WORKS, LTD. and get an error value of 1.55% with a module efficiency of 98.45% in the illumination test. Measurement results The illumination test on the x-ray plane's suitability test module gets a value of 188 lux and the test results get 153 lux where the difference between the backlight and collimator light is more than 100 lux there is a Phillip X-ray plane. Then the value of 202 lux is obtained and the test results are 167 lux where the difference between the backlight and collimator light is worth more than 100 lux, there is an X-ray plane with the Ecoview Ultra 200 brand.

This research revealed a gap between expectations and reality at the time of data collection. There are several suggestions for further research development, namely replacing the light sensor with a sensor that has a lower reading range. Furthermore, adding a programme that can process test result data directly in excel so that there is no need to fill in the test result sheet manually. And the last is to add a display on android, and change the size and design of the tool to make it smaller.

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