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Flatness and Alignment Analysis of Conformity Measuring Instrument Design in X-Ray Modality

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ABSTRACT A surface's verticality or horizontalness can be determined as well as its flatness using a waterpass or spirit level. The alignment and flatness of the X-ray tube and bucky table, which determine the perpendicularity of the X-ray beam, is one of the factors for the Conformance Test, according to PERKA BAPETEN No. 2 of 2018. A traditional waterpass is typically used to obtain that conclusion, but the measurement outcome is still subject to human error because there is no set value. To aim for exact alignment, A digital waterpass using the MPU6050 sensor is made, which produces precise X-Ray images, reduces noise in the form of shadow magnification, and investigates the function of the waterpass in the compliance of the X-Ray unit. Arduino is used as the data processor in this investigation. The output is then shown on an LCD and transmitted over Bluetooth to a computer where it is displayed using Delphi before being saved in Excel. With the deviation standard value of 10 degrees, we have obtained an error value from this research between 2% and 3%, minimum, which is 0.04 for sensor 1 and 0.25 for sensor 2. Sensors 1 and 2 measure 14 degrees at 0.089 and 0.054, respectively. The MPU6050 sensor can be utilized in this study to determine how flat the X-Ray tube and bucky table are about one another. This study's contribution is anticipated to be more effective tool testing, and the data will be kept on file until the next testing session.

INDEX TERMS water pass, conformity test, mpu 6050, gyroscope

I. INTRODUCTION

The X-ray machine is a tool used to diagnose disease or abnormalities in the patient's body. Rays are then emitted from an x-ray-generating tube and directed at the body part to be diagnosed. The beam will then penetrate the patient's body and will be captured by the film so that the film will create an image of the irradiated body part. To get quality image results, it is necessary to carry out a conformity test on an x-ray machine[1]–[3]. A conformance test is a set of test procedures to check the reliability of the x-ray machine. One of these factors is X-ray beam collimation, which takes into account the beam's congruence and perpendicularity. The perpendicularity of the X-ray beam is very necessary because it involves the resulting image[4]–[6]. Problems that often arise related to these parameters are the occurrence of image shifts and anode focus which results in a less sharp, distorted, and ghosted image so that if this happens, re-irradiation must be carried out which causes unnecessary radiation to increase to the patient[3], [7]–[12]. As happened in a 2018 study where Kesawa Sudarsih et al stated that in RSUD K.R.M.T Wongsonegoro Semarang when performing a radiograph, the collimator area was set wide, did not match the size of the object, and the final result was cut off so the patient had to repeat the radiograph. These things can also be caused by the changing position of the collimator or the rotation of the X-ray tube which has a low level of flatness[13]–[15]. The tool used to measure the perpendicularity of this X-ray beam is a waterpass, which until now there are still many who use an ordinary waterpass which still has many risks, for example, e-reading errors for each person using it (human error), parallel levels and different perpendicularity due to the value of the flatness between the tube and the patient table is unknown[16][17], [18]. Regarding the Conformity Test of Diagnostic and Interventional Radiology X-Ray Aircraft, in line with BAPETEN Regulation No. 2 of 2018, if there is a deviation between the collimator light field and the anode-cathode X-ray beam (horizontal) or the up-down (vertical) axis, it must not exceed 2% of the focus distance to the FFD (Focus Film Distance) with the standard deviation tolerance is 3 degrees[19]–[22].

This research was conducted in 2013 by Hidayat Nur Isnianto and Ali Ridho where a digital waterpass was made using an accelerator MMA 7361L sensor to read x, y, z and using an ATmega8 microcontroller. From the results of testing the besting uprights and floor slopes, the average error value for the x-axis is 0.51% while for the y-axis is 0.49%[23]. In research conducted in 2018, Suryadi Hodeng and Nurlindasari made a tool in the form of a digital waterpass based on the ATmega16 microcontroller. The sensor used is the MMA 7260 accelerometer sensor which will use C language for programming on the Vision AVR. The result is then displayed through a 2 x 16 LCD which shows the value of the object's slope[24]. Dewi Anggaraeni, et al. In 2018 made an angular velocity measuring device using two sensors, namely MPU 6050 and ADXL 335. The two sensors were integrated into Arduino to get an output value, then these values were processed and used as input for simulations that would later be carried out in MATLAB. The results obtained, MPU 6050 has a better performance because of the higher PDF value rated at an angular velocity of 18.04° per second and a smaller output range[25]. In 2020, Hendri Refsyi Saputra made a digital waterpass with an MMA 7361 acceleration sensor and processed it using an ATmega32 microcontroller, then an MP3 player as sound output that reads ngle has been reached and angle has not been reached then the slope level is displayed on the LCD. The output data from the accelerator sensor is data that is not linear, which must then be linearized with the equation y = mx + b. For 0° servo rotation, the required pulse width is 24 m/s (T on). This pulse width is used to measure a predetermined angle. In the measurement results, the average error of the spirit level is 1.37° with arc and 2.91° with mathematical theory. One of the causes of the error value is due to human error in the placement of the arc and ruler[26]. Lantika Anastasia Tinambunan makes a digital waterpass that functions to support calibration activities where this tool measures the slope of a field as well as calibrates and recalibrates[27]. The author uses the MPU 6050 sensor (Acceleration and Gyroscope), ATmega 328 microcontroller for processing, and 16 x 2 LED as output. The weakness of the research in 2013, 2018, and 2020 is that it still uses only the accelerometer sensor, where the sensor is still a bit slow to respond to fast movements. The author uses the MPU6050 sensor to get an accurate angle value using a gyroscope sensor Hendry Refsyi's Research in 2020 already used MPU6050 but still used 16X2 LEDs as output and no storage. The main purpose of the study is to develop and validate a digital waterpass using the MPU6050 sensor for precise measurement of the alignment and flatness of the X-ray tube and bucky table in an X-ray unit. The study aims to address the limitations of traditional waterpass methods, which are susceptible to human error due to the lack of defined set values. By introducing a digital waterpass with automated measurements and objective data processing, the research seeks to improve the accuracy of X-ray unit testing and enhance the quality of X-ray images. The ultimate goal is to contribute to better patient care outcomes by ensuring reliable diagnostic imaging and compliance with regulatory standards for X-ray equipment. Additionally, the study explores the potential for cost-effective and practical solutions for X-ray unit testing, with the aim of facilitating broader adoption of digital measurement technologies in radiology practice. The study's contribution lies in several key aspects that advance the field of radiology and X-ray unit testing:

a. Development of a digital waterpass using the MPU6050 sensor offers a precise and accurate method for determining the alignment and flatness of the X-ray tube and bucky table in an X-ray unit. This level of precision is crucial for ensuring the perpendicularity of the X-ray beam and reducing distortions or shadows in the resulting images.
b. By providing more accurate measurements and reducing human error, the digital waterpass contributes to improved X-ray image quality. Enhanced image accuracy can lead to more reliable diagnoses, minimizing the risk of misdiagnoses, and facilitating more effective patient care.
c. The study's implementation aligns with the requirements outlined in PERKA BAPETEN No. 2 of 2018, which mandates conformance tests for X-ray units. The digital waterpass allows healthcare facilities to meet these regulatory standards efficiently and effectively, ensuring the safety and compliance of their equipment.
d. The study's use of Arduino for data processing and Delphi for visualization and storage in Excel format ensures that measurement data is recorded accurately and kept for future reference. This contributes to the creation of a comprehensive database for X-ray unit performance assessment, facilitating ongoing maintenance and quality assurance.
e. The development of a digital waterpass using readily available components like the MPU6050 sensor and Arduino suggests a cost-effective and practical solution for X-ray unit testing. This potential for wider adoption can benefit healthcare facilities with limited resources or those seeking to upgrade their testing methods.

Overall, the contribution of this study lies in its innovative approach to X-ray unit testing, offering a precise and practical solution for measuring alignment and flatness. The potential improvements in image quality, patient safety, regulatory compliance, and data management make this research valuable to the field of radiology and hold promise for further advancements in the future.

II. MATERIALS AND METHOD

The investigation is being done experimentally. The writer suggested a wireless conformity test tool to measure the flatness of both the x-ray tube and the bucky table. The next section will go over the supplies and the procedure.

A. DATA COLLECTION

The researchers compared the designs in this study. (Wireless Conformity Test Tool) with a commercial waterpass as well as the waterpass that is already inside the X-Ray machine as a comparison device. This study also uses a beam alignment test tool to see does the x-ray tube beam shoots straight on the focus point. The X-Ray machine that this study uses is from the brand Ecoview. This study uses two MPU6050 sensors as a gyroscope sensors that will be put on the bucky table an on the X-Ray tube (as shown in FIGURE 1), Using an Arduino Mega 2560 as a microcontroller and an HC-05 to transmit data to a PC. This study also uses LCD and Delphi software to display the value.

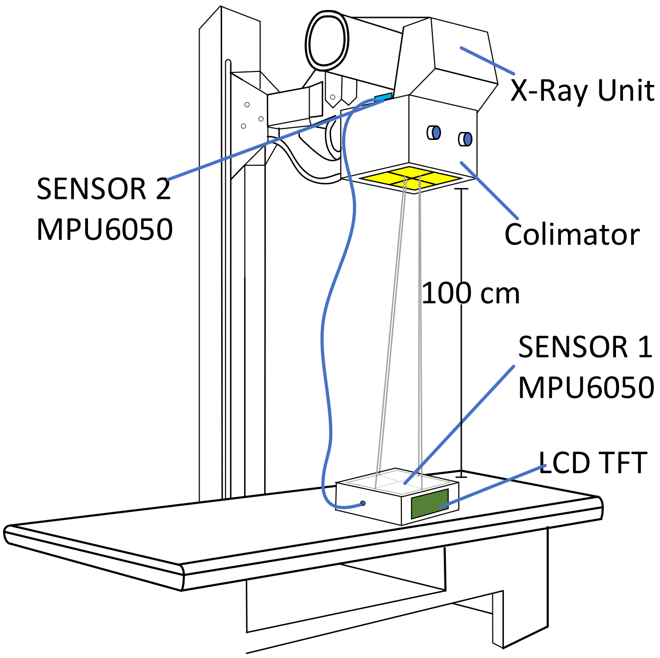


FIGURE 1. Visualization of how the sensors will be put in the X-Ray unit.

Initially, the tool underwent tests to ensure its accurate measurement of surface flatness. This was achieved by conducting two different evaluations: first, by tilting both the X-ray tube and bucky table by 10 degrees, and second, by tilting only the X-ray tube by 14 degrees. The data was collected five times for each test and compared with measurements from a digital protractor. The data readings were conveniently displayed on an LCD integrated into the tool, offering real-time access to the results. Additionally, the data could be accessed and stored on a PC via the HC-05 Bluetooth module. Establishing communication between the PC and the tool required a connection to the tool's Bluetooth, enabling the seamless display of values in real-time through the Delphi software. For data preservation and future reference, the Delphi software included a "save" option, enabling users to save the measurement results in an Excel format. This feature ensures that the data can be easily accessed and analyzed beyond the real-time display, contributing to the overall reliability and practicality of the tool.

At first, the tool is put to the test if it can work to measure the flatness of a surface properly, it is done by two ways, measuring the flatness by tilting both the x-ray tube and bucky table by 10° and then measuring the flatness with only tilting the X-Ray tube by 14°. The data was then taken 5 five times and compared with the digital protractor. The data can be seen through the LCD that is placed on the tool, the data can also be accessed from a PC through the HC-05 Bluetooth module. To start the communication, the PC and the software Delphi should connect to the tool's Bluetooth, and then the values will be displayed there in real-time. There will also be a "save" option in the software to save the result of the data in excel.

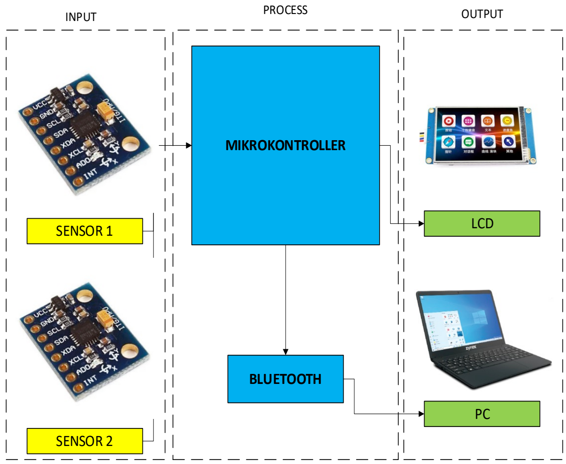


FIGURE 2. The proposed design of wireless digital waterpass using Bluetooth connection to PC. The microcontroller that was used was Arduino Mega 2560 and HC-05 Bluetooth module as the communication between the tool and PC.

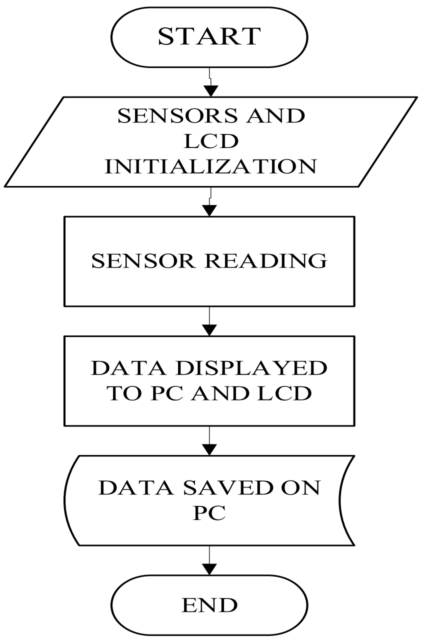


FIGURE 3. The flowchart of the system detects the flatness of the surface, in this case, x-ray tube and bucky table.

After knowing that the sensors are working properly by doing a simple test that was mentioned above, come to the next step which is analyzing how a slanted X-Ray tube would affect the imaging result. To have a better understanding of how this proposed design works, FIGURE 2 shows the block diagram of the system, and FIGURE 3 shows the flowchart of the system.

Continuing to the next data collection, first, we align the x-ray tube and bucky table perpendicularly against each other to get zero degrees of tilt. After that, a self-made beam alignment test tool is put right in the center of focus with the help of collimator test tool, as shown in FIGURE 4. Then x-ray beam is shot. From there, the distance from the focus point to the slanted point can be measured using formulas to determine how many degrees is the slant and does the result can pass the test. Those procedures are then repeated in two different degrees, which is 3 and 5 degree.

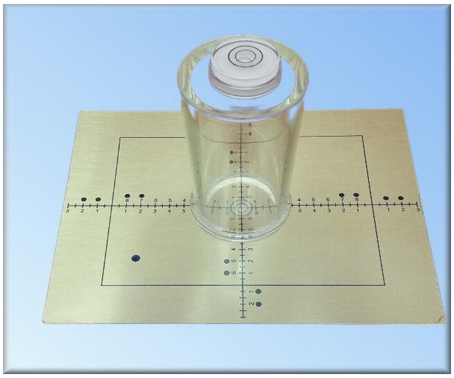


FIGURE 4. Visualization of how the beam alignment and collimator test tool is placed above the x-ray tube on the bucky table.

B. DATA ANALYSIS

Temperature, humidity, flow, and noise measurements were taken 20 times for each parameter. By applying Eq. (1), the mean or average is used to determine the mesurement's average value :

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

where x represents the mean (average) value for the first n measurements, x1 represents the second, and xn represents the nth measurement. The standard deviation is a number that represents how much variance there is in a set of data or a standard deviation from the mean. Eq. (2) can be used to display the standard deviation (SD) formula :

$$X = \sqrt{\frac{\Sigma(Xi - X)^2}{n-1}} \quad (2)$$

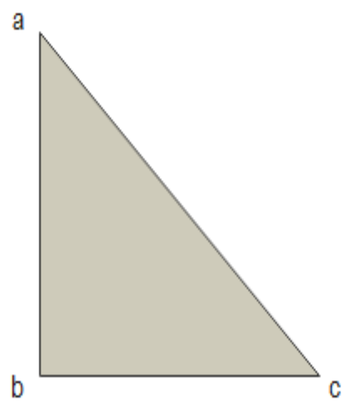
where xi is the percentag of the intended values, x denotes the measurement results' average, and n denotes the total number of measurements. Doubt that may be shown in each measurement result is called uncertainty (UA). In equation (3), the uncertainty formula is displayed :

$$UA = \frac{SD}{\sqrt{n}} \quad (3)$$

where UA denotes the measurement's overall level of uncertainty, SD depicts the measurement's standard deviation as a result, and n denotes the total amount of measurement. The system error is displayed by the % error. The lesser amount The difference between each data set's means is the error. The mistake might demonstrate how the model or design deviates from the norm. Equation (4) displays the error formula.

$$ERROR = \frac{(Xn - X)}{Xn} \; x\, 100\% \quad (4)$$

where Xn represents the value that the calibrator machine measured. The value determined from the design is the x. To calculate the angle obtained from the focal spot and slanted spot, these formulas are used Imagine Pythagoras's triangle:



where a indicates the angle that needs to be calculated, ab indicates the height of the beam alignment test tool, and bc shows the distance between the focal spot and slanted spot.

First, before calculating the a angle, find the ac value, apply this equation (5) and (6):

$$ac = \sqrt{(ab^2 + bc^2)} \quad (5)$$

and then to find the a angle:

$$a = Ar^{-sin}\left(\frac{bc}{ac}\right) x \sin b \quad (6)$$

C. RESULT

For the measurement which was taken 5 times with both the x-ray tube and bucky table being tilted 10 degrees, we found out that the error values range between 0.02% - 0.03% for both sensors as shown in TABLE 1. And then for the 14 degrees tilted x-ray tube, for sensor 1 (bucky table) has 0.01% to 0.03% error value and as for sensor 2 (bucky table) has 0% - 0.01% error value as shown in TABLE 2. The tool is compared with a digital protractor or a digital waterpass.

TABLE 1
The comparison measurement between the design and digital protractor in the 10° set point for both sensors. The measurement was performed five times. (DP: Digital Protractor)

Sensor	Measurement (°)					Mean	SD	UA
	1	2	3	4	5			
Setting	10							
DP	10	10	10	10	10	10		
S1	10.3	10.2	10.2	10.2	10.2	10.22	0.04472	0.02
Error S1	0.3	0.2	0.2	0.2	0.2	10.22		
S2	9.7	10.3	10.2	10.3	10.2	10.14	0.25099	0.1122
Error S2	0.3	0.3	0.2	0.3	0.2			

TABLE 2
The comparison measurement between the design and digital protractor in the 0° set point for sensor 1 and 14° for sensor 2. The measurement was performed five times. (DP: Digital Protractor)

Sensor	Measurement (°)					Mean	SD	UA
	1	2	3	4	5			
Setting	14							
DP	0.3	0.5	0.3	0.3	0.3	0.2		
S1	0.3	0.5	0.3	0.3	0.3	0.3	0.089443	0.04
Error S1	0.1	0.3	0.1	0.1	0.1			
DP	14	14	14	14	14	14	0.054772	0.024
S2	14.1	14	14.1	14	14	14.1		
Error S2	0.1	0	0.1	0	0			

For the next measurement which is the effect of slanted x-ray tube towards the image result, the tool is compared with a digital protractor and the waterpass that is installed inside the x-ray unit. The first research is making the x-ray tube perpendicular towards the bucky table which means it is being put in 0 degree flat, the result shows 0.04% error for sensor 1, and 0.02% for sensor 2, as shown in TABLE 3. Meanwhile the results of the imaging, in FIGURE 5, after being calculated with equation number 4 and 5, we have the result of 1.71 degree which still pass the requirements of the conformity test. For the 3° result, we only use the second sensor which from the measurement have 0% of error, as shown in TABLE 4. And as shown in FIGURE 6 with 4 mm as the length between the focal and slanted point, we got the result of 4.72° which shows that it doesn't pass the conformity test requirements. As for the last testing, the 5° angle, the result shows 0.02% of error as shown in TABLE 5 and the length between the focal and slanted spot is 16 mm as can be seen in FIGURE 7 and using the 4th and 5th equation, we found 6.08° as the angle which doesn't pass the conformity test requirements.

TABLE 3
The comparison measurement between the design and x-ray unit waterpass in the 0° set point.

X-Ray *Tube* installed waterpass angle	Digital waterpass (research tool)		Error	
	Sensor 1	Sensor 2	Sensor 1	Sensor 2
0°	0.49°	0.2°	0.49°	0.2°

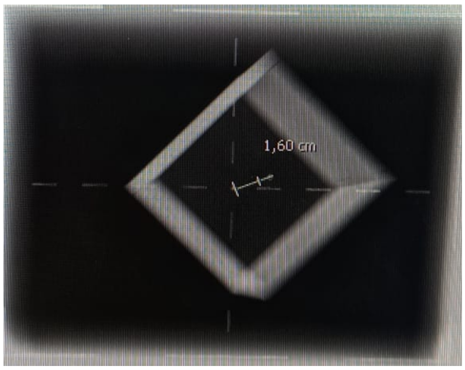


FIGURE 5. **In this figure shows the image result using beam and collimator test tool, we can see the focal spot (center dot) and slanted spot. That distance will then be measured and calculated by no 4 and 5 equations to get the actual angle.**

TABLE 4
The comparison measurement between the design and x-ray unit waterpass in the 3° set point.

X-Ray *Tube* installed waterpass angle	Digital waterpass (research tool)	Error
	Sensor 2	Sensor 2
3°	3.00°	0%

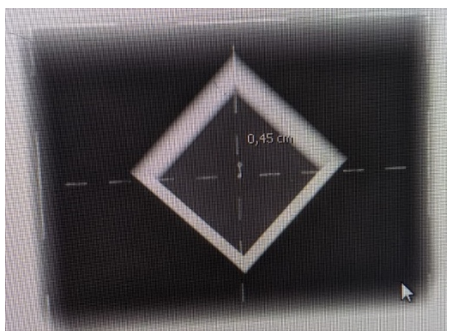


FIGURE 6. **In this figure shows the image result using beam and collimator test tool if the angle was tilted by 3°.**

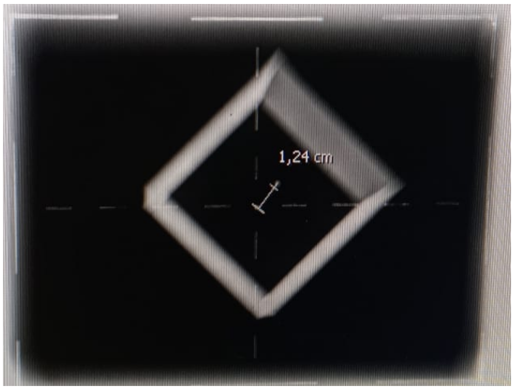


FIGURE 7. In this figure shows the image result using beam and collimator test tool if the angle was tilted by 5°.

TABLE 5
The comparison measurement between the design and x-ray unit waterpass in the 5° set point.

X-Ray *Tube* installed waterpass angle	Digital waterpass (research tool)	Error
	Sensor 2	Sensor 2
5°	4.80°	0.20°

D. DISCUSSION

The provided passage discusses the results of a study that developed a design to measure the flatness angle of a surface, specifically the x-ray tube and bucky table from an x-ray tube unit, to support the x-ray conformity test. The design uses two MPU 6050 sensors to measure the angle, and the results are displayed on a liquid crystal display (LCD) and transmitted to a PC via Bluetooth using the HC-05 module. The software used to show the data on the PC is Borland Delphi, which allows users to view and save the data in Microsoft Excel format. To evaluate the accuracy of the proposed design, the researchers compared it with a commercial digital protractor and the waterpass installed in the x-ray unit used in the study. The errors were measured for both sensor 1 and sensor 2 at different angles, and the results were as follows. Sensor 1: Smallest error: 0.02% at 10 degrees and 0.01% at 0 degrees. Biggest error: 0.03% at both 0 degrees and 10 degrees. Sensor 2: Smallest error: 0%. Biggest error: 0.02% at 10 degrees and 0.01% at 14 degrees. The study also assessed the imaging results at various tilt angles of the tube, specifically at 0 degrees, 3 degrees, and 5 degrees. The final angle results for the imaging were as follows:

a. 0^{0} tilt: 1.27 degrees (still tolerable and passing the conformity test).
b. 3^{0} tilt: 4.72 degrees (does not pass the conformity test).
c. 5^{0} tilt: 6.08 degrees (does not pass the conformity test).

The passage further emphasizes that the image result at 5 degrees tilt was particularly distorted, which could lead to misdiagnoses by doctors or necessitate the patient redoing the imaging, resulting in unnecessary additional radiation exposure.

The limitation of the study are that the MPU 6050 sensor fluctuates a lot and the design of the tool is quite big. The making of this device based on wireless can be used as a tool to support the conformity test to reduce the probability of human error and to acknowledge the definite value of surfaces' flatness so that we can make sure that the tube and bucky table are flat and perpendicular against each other, therefore there will be no distortion or shadows that can be seen from the image result and no patient would need to repeat the imaging process. Therefore the tool design can be made more compact and the sensor used has a smaller range.

E. CONCLUSION

This study aims to make a digital waterpass that can support the x-ray conformity test to reduce the probability of human error and to acknowledge the definite value of surface's flatness so that the image will have no shadows or distortion that the patient would only need to do one time imaging process. From this study, we have gotten the biggest error result of 3% and the smallest result of error of 2% which shows that this proposed design can be used to measure flatness in two places at the same time. For future development, using a gyroscope sensor that doesn't fluctuate too much and with smaller and compact size should be proposed; thus, we will be able to see the exact value without it being changed for a couple of seconds before it's fixed to the exact value.

From the research found a gap between expectations and reality at the time of data collection. For further research development can be done. first, Replace the gyroscope sensor with a sensor that has a lower reading range. Adding a program that can process test result data directly in excel so there is no need to manually fill in the test result sheet. Adding a display on android. Change the size and design of the tool to make it smaller

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