Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCV

by

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APPROVAL SHEET

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Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCV

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***Abstract*—The commonly used method to measure the Cobb angle is by manually performing the pencil and protractor method, which a doctor supervises. The study aims to create a device that can automatically compute the Cobb angle and classify scoliosis, whether thoracic, lumbar, thoracolumbar, or combined scoliosis, by capturing X-ray images using YOLOv3 and OpenCV. The experiment is conducted by training X-ray images to include in the algorithm for detecting the spine. Then, the Cobb angle is calculated through the lines obtained from polynomial curve fitting and inflection points. From this, the angle classification is drawn. The Cobb angles are subjected to a two-tailed paired t-test with a significance level of 2.5%. A statistical value of 0.213 is computed, which is less than the critical value of 2.228. According to the results, the statistical test proves that the research's device is equally effective as the pencil and protractor method in determining the Cobb angle and its classification.**

Index Terms—Cobb angle, scoliosis, YOLOv3, OpenCV, angle classification

I. Introduction

Scoliosis is a disorder in which the spine will form a curvature, often S-shaped or C-shaped, that people of different ages can have. The most common type is—Adolescent Idiopathic Scoliosis (AIS)—caused by unknown factors which occur most often just before the age of puberty, typically in children ages 10 to 12 and in their early teens [19]. Symptoms of scoliosis can include: asymmetrical shoulders, uneven waist, one hip can appear higher than the other, a lump on one side of the chest, and shortness of breath and chest pain from heart and lung problems. Scoliosis is a three-dimensional deformity of the ribcage and spine that modifies the form of the trunk because of a sideway deformation of the spine that can be considered pathologic when it is >10° using the Cobb angle technique [14].

Scoliosis usually affects 2%-4% of adolescents, and 70%-80% of cases are unknown [6]. Because of this, early detection is necessary, especially during the early years, to prevent further deterioration of the spine. Furthermore, if the scoliosis is diagnosed to have a Cobb angle of 40° or less, the condition is reversible by physical therapy or braces. However, scoliosis may be irreversible and can only be treated by surgery if the Cobb angle is greater than 40° [5]. Doctors first perform a physical examination to diagnose a patient has scoliosis by observing the body for any abnormal curves or physical deformities by letting the patient do a series of range of motion tests. They then perform Adam's forward bend test where the doctor will stand behind the patient, look along for any abnormalities in the spine, and measure the rotation of deformity using a scoliometer to determine if the patient needs radiography [12]. A radiographic examination is done every six months to check spinal health. However, being frequently exposed to radiation caused by the X-ray examinations may have more severe implications to the patient's health, such as being a candidate for cancer [2][7][14]. After obtaining the patient's X-ray, doctors will then determine the severity of scoliosis based on the angle of its curve, which is called the Cobb angle [20]. The measured angle between the most slanted bones in the spine structure is the Cobb angle, wherein the type of curve can then be determined based on the number of curves along the spine and their position [14]. Manual measurement of the spine curvature needs considerable effort and time; that is why research is done to automate its process.

Today's commonly practiced method to measure the Cobb angle uses the pencil and protractor method. The technology that can automatically compute the Cobb angle and classify the scoliosis is not available in every hospital. Because of this, a device that can automatically compute for the Cobb angle by capturing X-ray images of scoliosis patients may provide the needs of those hospitals that need the automated technology.

The primary objective of this research is to be able to detect and classify scoliosis based on the chest X-ray by (1) creating a device that can capture X-ray images, (2) training an algorithm to automatically detect the spine structure in X-ray images, (3) compute for the Cobb angle based on the detected spine, and classify scoliosis according to its angle classification whether thoracic, lumbar, thoracolumbar, or combined scoliosis, and by verifying the Cobb angle and classification using T-Test.

This study will benefit the orthopedic doctors in terms of saving their time solving the cobb angle since the calculation will now be automated instead of using the pencil and protractor method. Hence, more patients can be accommodated. Government agencies such as DOH and the Department of Science and Technology may use this device to expand their research. The National Council for Disability and Affairs may also use this for screening and intervention projects. Numerous Philippine medical facilities may also use this device, such as the Philippine Orthopedic Center and Philippine General Hospital.

The design will consist of a Raspberry Pi and a camera module. The vertebrae detection training algorithm, image processing, Cobb angle calculation algorithm, and GUI will be coded using the python programming language. The vertebrae detection will be limited to chest X-ray images only. It will also be limited to patients who have thoracic, lumbar, thoracolumbar, or combined scoliosis, which means those who have lordosis (spine bending backward) and Kyphosis (spine bending forward) will not be part of the study.

II. METHODOLOGY

YOLO, short for "You Only Look Once," is a neural network that works upon Darknet. YOLOv3 is the most updated version that uses Darknet with 53 convolution layers [20]. Bounding boxes are used in training YOLO to detect objects. Then, a collection of images that are to be detected are inserted to train the said algorithm. Training images must have the object be bounded by a box so that the algorithm can locate the object within the image. After the annotation of the bounding boxes, Google Colab can aid in the YOLO training of the images [16]. Deep learning convolutional neural networks are needed to assess the severity of scoliosis by detecting and segmenting the vertebrae and measuring the Cobb angle [3]. Polynomial curve fitting was also used to create spine lines and image manipulation to separate each vertebra. In [9], they utilized the YOLO neural network on a Raspberry pi with a webcam attachment to recognize and locate household objects in the webcam video. YOLO is capable of multi-class objects, which allows it to detect multiple objects on an image or video [1][17][21]. OpenCV (Open-Source Computer Vision Library) allows the computer to understand images and videos, and is often used for machine learning and artificial intelligence to detect faces, objects, process images, analyze videos, and automate tasks [10][15].

Moreover, OpenCV is known for its efficiency and efficacy in delivering effective frame rate results for Raspberry Pi [11]. It is also used in image and video detection programmed in Python [8][4]. A tangent line is drawn on the most deviated vertebrae, then the angle computed between the two lines is the Cobb angle. In [13], they used inflection points to determine the two deviated vertebrae. They then created perpendicular lines at these points and used equation 1 to calculate the angle between two lines to get the Cobb angle. The inflection points are points where the curve changes from a concave downward curve to a concave upward curve (or vice versa).

A. Conceptual Framework

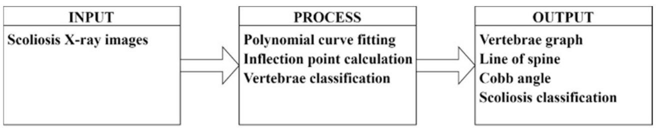

Fig. 1. Conceptual Framework

Fig. 1, the study's conceptual framework illustrates the designed device's input, process, and output. In the input, the scoliosis X-ray images are captured using the Raspberry Pi camera module.

In the process part, classification of vertebrae is done on the training images to allow the algorithm to know where the vertebrae are located. Polynomial curve fitting is used on the coordinates that the algorithm will detect to form a line that will follow the spine on the X-ray. The inflection points found on the spine line will help detect the deformed vertebrae in the spine.

In the output, using the algorithm on the taken scoliosis X-ray outputs the coordinates of the vertebrae in the spine. The polynomial curve fitting, using the coordinates of vertebrae as inputs, results in the spine line. Inflection point detection in the spine line results in the Cobb angle. And based on the Cobb angle, classification of scoliosis can be done.

B. Hardware Development

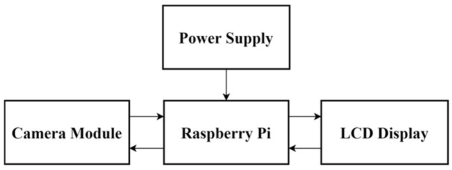

Fig. 2. Block Diagram

In Fig. 2, the power supply is a charger connected to a 220V electrical socket that automatically outputs a 5V 3A / 9V 2.0A / 12V 1.5A power supply to the Raspberry Pi. The camera module and LCD will get their power from the Raspberry Pi. The Raspberry Pi serves as the system's brain and will instruct the operation through its logic program. The image feed from the camera module will be input and processed through the algorithm and training processes programmed in the Raspberry Pi. The results will be displayed on the LCD together with the application.

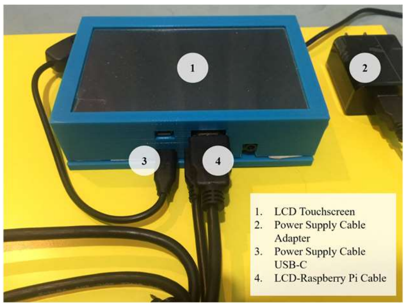

Fig. 3. Device Set-up Front View

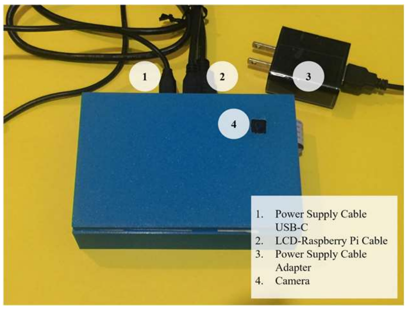

Fig. 4. Device Set-up Back View

Fig. 3 and Fig. 4 show the set-up of the device where the LCD touch screen and Raspberry Pi are enclosed inside a blue-colored case. The LCD screen is 5 inches in length, and the camera (black) protrudes from the backside of the blue-colored case.

C. *Software Development*

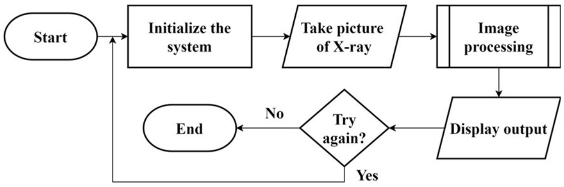

Fig. 5. Software Development Flowchart

Fig. 5 shows the software development flowchart. It starts by initializing the system making sure that all necessary components are correctly connected. The camera module of the system can be used to take a picture of an X-ray. The image processing will then take place, where it will read and manipulate the image to get the details and coordinates of the spine in the X-ray. The spine line can be calculated using the coordinates and polynomial curve fitting. The inflection points can then be obtained using derivatives on the function—the inflection points show where the spine deviates and forms a curve. A tangent line can be created from the inflection points and using equation 1, which can calculate the angle between the two lines, the Cobb angle can be obtained. After that is done, it will display the results of the Cobb angle calculation and the classification of scoliosis, whether it is thoracic, lumbar, thoracolumbar, or combined scoliosis. The classification of scoliosis will depend on the value of the Cobb angle obtained.

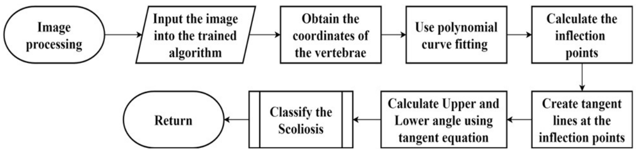

Fig. 6. Image Processing Flowchart

Fig. 6 shows the image processing of the system. After taking an X-ray picture, the image will be passed to the trained algorithm to locate each vertebra. Then the algorithm will place a rectangle on each of them. The coordinate of each rectangle drawn by the algorithm will then be obtained and used to locate the center of each rectangle. After that, polynomial curve fitting can calculate the spine line's function and draw it on the image. The inflection points will then be calculated, which will show the deviated vertebrae in the spine. In cases with more than one Cobb angle, such as in combined scoliosis, the inflection points will still show the deviated vertebrae. A tangent line can be drawn using the spine's line function and inflection point. The Cobb angle between two tangent lines is calculated using Equation 1. In cases two Cobb angles are calculated, these can be considered the upper and lower angles. After that, it will enter the classification subroutine, and based on the value of the cobb angle; scoliosis can be classified, whether it is thoracic, lumbar, thoracolumbar, or combined scoliosis.

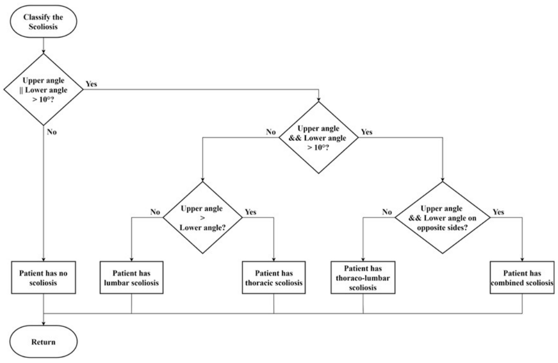

Fig. 7. Scoliosis Classification Subroutine

Fig. 7 shows the scoliosis classification subroutine of the system. It will first go to the first decision box, which will check if either the upper angle or lower angle is greater than 10°; if both fail the condition, then the patient has no scoliosis. In comparison, if any of the two angles is greater than 10°, it will move onto the second condition. The second decision box will check if both angles are greater than 10°. Suppose either one of the angles is lower than 10°. In that case, it will move onto the third decision box, where it will check whether the top angle is larger than the lower angle if the upper angle is less than the lower angle. The patient has lumbar scoliosis; if the top angle is larger than the lower angle, the patient has thoracic scoliosis. If both angles pass the condition in the second decision box, it will move onto the fourth decision box. It will check if the upper and lower angles are on opposite sides; this can be checked by comparing the coordinates of their lines and intersection. If both angles are on the same side, the patient has thoracolumbar scoliosis, while on opposite sides, the patient has combined scoliosis. After that, it will return to the parent subroutine, Image processing.

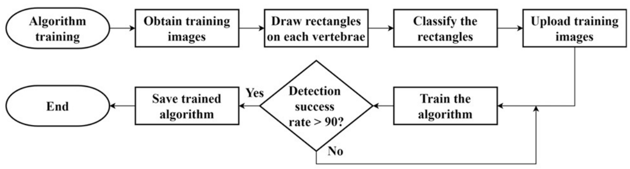

Fig. 8. Algorithm Training Flowchart

Fig. 8 shows the training algorithm for the system. The researchers gathered 400 training images of scoliosis X-rays for the algorithm training. The training images can be acquired in SpineWeb, an online collaborative platform that hosts several datasets supported by institutions such as the National Institutes of Health. Training images from SpineWeb have dimensions of 900x1900 pixels. Alternatively, training images can also be acquired from similar research that shares their database publicly. The researchers will then have to place a rectangle on each vertebra on every spine in the X-rays, which will act as bounding boxes for the algorithm. The researchers will then classify the boxes as vertebrae. After that, the training images will be uploaded to the algorithm. During the training, the YOLO architecture will look through each training image along with the bounding boxes placed by the researchers. The image is divided into several regions by the algorithm; then, the algorithm predicts the bounding boxes and probabilities for each area. The process will continue until the algorithm has a greater than 90% success rate of locating vertebrae. The weights of the algorithm will be saved and used on the image processing algorithm and will help automatically find the vertebrae in different X-ray images.

Fig. 9. Graphical User Interface

Fig. 9 is the Graphical User Interface (GUI) of the application for the system. GUI is built using PyQt, a free GUI toolkit that uses python as a programming language. On the left side is a panel that contains the Capture, Save, File, and Reset buttons. The Capture button will start the device's camera module, allowing the user to take a picture of the X-ray for the input image. The File button will allow the user to search for the X-ray picture in the device's storage instead of taking a picture. The Save button will allow the user to save the output image of the system as well as the cobb angle and classification. The Reset button will clear the values from the window, allowing the user to start again. On the right-side panel, the output part of the software can be seen. The input image (left image) box is where the taken X-ray picture will be placed. The output image box (right image) is where the resulting image will be placed; it will show the calculated lines and angle. Once the input image box is filled, the Calculate button can be pressed to start the image processing and Cobb angle calculation algorithm. Additionally, the output panel will show the calculated Cobb angle and classification of scoliosis.

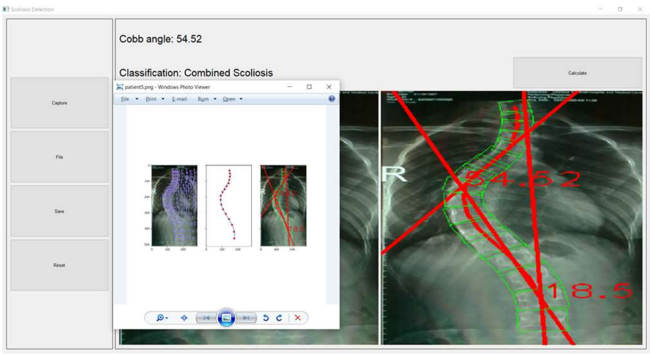

Fig. 10. The output of the system

The window in Fig. 10 shows the system's output. The whole spine in the X-ray must be captured and centered when using the device. On the left side is the output image of the trained YOLO algorithm; it can detect the vertebrae in the spine and output the coordinates in the image. In the center image, using the coordinates calculated by the YOLO algorithm, the center of the bounding boxes can be obtained. By inputting the coordinates of the center into a polynomial curve fitting function of python, the function of the spine line is acquired. The program draws the line on the x-ray image as seen on the right image. Then the program calculates inflection points by getting the first and second derivatives of the line function. The inflection points will locate the deformed vertebra in the spine. The program will draw the lines at the inflection points of the curve. The device will calculate the lower angle using equation 1. Equation 1 uses the slopes (m_1 and m_2) of the two tangent lines to determine the angle between them.

$$\theta = tan^{-1}\left|\frac{m_1 - m_2}{1+m_1 m_2}\right| \quad (1)$$

The same process can be done to obtain the upper angle of the spine. Then, the system will then classify scoliosis according to the calculated upper and lower angle, and the highest Cobb angle value will be displayed. The system will then output the right image into the GUI.

III. Results and Discussion

A. Data Gathered

For the testing and evaluation of the system, the following Cobb angle readings and the doctor's findings are tabulated below in Table 1.

TABLE I
SUMMARY OF THE DATA RECORDED FROM THE DOCTOR AND THE SYSTEM

	Doctor's Findings		System's Findings	
X-ray	Cobb Angle	Classification	Cobb Angle	Classification
1	16°	Thoracic	14.86°	Combined
2	8°	No scoliosis	9.45°	No scoliosis
3	11°	No scoliosis	9.55°	No scoliosis
4	32°	Thoracic	35.25°	Combined
5	53°	Combined	54.52°	Combined
6	25°	Combined	23.43°	Combined
7	22°	Thoracic	20.03°	Thoracic
8	33°	Lumbar	34.15°	Combined
9	22°	Lumbar	21.55°	Lumbar
10	30°	Lumbar	29.78°	Lumbar
11	20°	Lumbar	18.22°	Lumbar

B. Statistical Treatment

Since the Cobb angle results from this study's system and the results from the X-ray images are two (2) related samples and are from the same group of X-ray images, a Paired T-test is used. A T-test is used to check if two (2) means are reliably different. A Paired T-test is used when one (1) group of people are tested at two (2) different times, or it tests the means of the group twice. It is also applied in comparing two different measurement methods applied to the same subjects. In the case of this research, different ways of Cobb angle measurement are done on X-ray images. The measurements are verified using a Paired T-test to get the p-value and conclude the study's hypothesis.

The null hypothesis, $H_o: \mu_d = 0$, is that the Cobb angle measuring system proposed in this study has no significant difference to the measured Cobb angle by the doctor. The alternative hypothesis, $H_a: \mu_d \neq 0$, is that there is a substantial difference in the accuracy of the two approaches. If $|T| > |T_{crit}|$, H_a is rejected, then the difference is significant.

TABLE II
DIFFERENCE OF COBB ANGLES USING PAIRED T-TEST

X-ray	System Cobb Angle x_i	Measured Cobb Angle y_i	Difference d_i
1	14.86°	16°	1.14
2	9.45°	8°	-1.45
3	9.55°	11°	1.45
4	35.25°	32°	-3.25
5	54.52°	53°	-1.52
6	23.43°	25°	1.57
7	20.03°	22°	1.97
8	34.15°	33°	-1.15
9	21.55°	22°	0.45
10	29.78°	30°	0.22
11	18.22°	20°	1.78

By performing a paired t-test using the values above that are shown in Table 3, the mean difference ($\bar{d}$) is 0.11, with a standard deviation of differences (s_d) of 29.332, getting a t-statistic (T) of 0.213. Using the t-distribution table, comparing the t-statistic with the T-critical (T_{crit}) of 2.228, which is found under the $t_\alpha = 0.025$ column, following a p-value of 0.05, and degrees of freedom of 10. The results show that the t-statistic is less than the t-critical value, failing to reject the null hypothesis. Hence, since the null hypothesis, $H_o: \mu_d = 0$, there is no significant difference in the accuracy of the two methods. The doctor's method, and the system's method, are equally suitable to measure the Cobb angle of the patients to help detect scoliosis and its classification.

IV. CONCLUSION

This study aims to automate the computation of the Cobb angle and the classification of scoliosis, mainly using the YOLOv3 Algorithm with OpenCV to help orthopedic doctors save their time to accommodate more patients. A device is created that can capture X-ray images, train an algorithm to automatically detect the spine's structure in X-ray images, and automatically compute for the Cobb angle and detect the classification of scoliosis, whether thoracic, lumbar thoracolumbar or combined scoliosis. The testing was performed by capturing the X-ray films using the device placed under a light source, and findings were recorded as shown in Table 1. Furthermore, the researchers conducted a paired t-test to compare the two different measurement methods applied to the same patients using the tabulated data. The computed t-statistic is 0.213, less than the t-critical, 2.228. The t-critical is based on the t-distribution table following a p-value of 0.05, a $t\alpha$=0.025, and degrees of freedom equal to 10. Based on the decision rule for the statistical analysis, the null hypothesis is not rejected; hence, there is no substantial difference in the accuracy of the two methods. In conclusion, using the device is just as effective as the pencil and protractor method for detecting and classifying scoliosis.

V. RECOMMENDATION

The researchers recommend capturing the X-rays films using a stand or holder to have a steady shot since the camera angle can affect the quality of the images, hence, affecting the calculations. Other versions of YOLO, such as YOLOc4, YOLOv5, and PP-YOLO, can also be installed in the device to see if it can improve the results and time for detecting scoliosis to provide both the doctor and patient fast and accurate results.

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Comparative Analysis between YOLOv3 and YOLOv4 for Scoliosis Detection

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***Abstract*—It is always of utmost priority to avoid the risk of developing scoliosis and other ailments that may come with it due to radiation exposure. The study aims to use and compare YOLOv3 and YOLOv4 to detect Cobb angle utilizing the device in the researchers' previous study, which used Raspberry Pi, OpenCV, and Python. The two algorithms are trained using different set images of scoliosis X-rays. The accuracy and speed between the two are gathered by determining which has the closest value to the doctor's value and the average execution time of both algorithms running on the device made by the researchers in the previous study. The results show that YOLOv3 has scored 8 out of 11 higher accuracy results than YOLOv4 using the same X-ray images of scoliosis. Moreover, YOLOv4 has a faster execution time with a 3.979% difference from YOLOv3.**

Index Terms— Scoliosis, YOLOV3, YOLOv4, accuracy, speed

I. INTRODUCTION

Object recognition or detection, which is the capability to identify objects or entities, has been built and used to aid in various fields such as medical imaging, face detection, and robotics. Object detection can be accomplished through machine learning practices and algorithms such as YOLO (You Only Look Once) [2]. The first version of YOLO is a high-speed one-stage detector based on deep learning, and through continuous, it has made it almost the best choice for object detection [7].

The developers of YOLO also stated that YOLO outperforms other detection models like Region-based Convolutional Neural Network (R-CNN) and Deformable Part Models (DPM) [12]. YOLOv3, released in 2018, has made significant progress in speed and accuracy but is still lacking in tracking small targets. YOLOv3 has several enhancements over YOLO and YOLOv2. It uses Darknet-53, which operates 53 convolutional layers making it more potent than YOLOv2's Darknet-19 [13]. Aside from this, YOLOv3 also uses automatic identifiers for multiple labels, used for databases that have similar labels [5]. On the other hand, YOLOv4, released in 2020, recognized this issue and developed this new version to have an effective and robust object detection model [15]. YOLOv4 employs post-processing methods they call "bag of specials" that increase the inference cost by a small amount, improving object detection accuracy. It trains faster than YOLOv3 and has an improved Average Precision (AP) of 10% and Frames Per Second (FPS) of 12%. Compared to another object detector model such as EfficientDet, YOLOv4 runs faster with comparable performance [2]. Scoliosis is diagnosed using radiography examination. Its severity can be measured by measuring the Cobb angle in the patient's X-ray, which is done by measuring the most tilted or angled vertebrae in the spine curvature [8][16]. If left untreated, it is a progressive deformation; hence, patients must be examined every 3-6 months to monitor and correct the progression. X-rays are a drawback since the patients will be exposed to multiple radiations, increasing the risk of cancer [1][4]. A study proposed an automatic scoliosis measuring system based on a deep learning algorithm [14]. Their design used U-net CNN to detect and segment the vertebrae in the spine radiographs. The segmented images identified the top and bottom end vertebrae to measure the Cobb angle in the X-ray images. Numerous vision-centered research used Raspberry Pi for biometric systems such as fingerprint detection and iris recognition [6]. Python is the primary programming language and a machine learning library for CNN when used with Raspberry Pi [11]. OpenCV is a machine learning library used in numerous image-processing applications and is known to shorten the development cycle and the camera calibration period [9]. It is also well-known to detect human body parts on images or videos [10]. Python, Raspberry Pi, a camera module, and OpenCV were used to create street lighting detection without requiring a high level of performance devices and complex algorithms; this makes it a cost-effective and straightforward solution to practice object detection [3].

YOLO is famous for its speed and accuracy and its different versions that have significant improvements over each release. Because of this, YOLOv4 will be used and compared with YOLOv3 to speed up the execution time and have more accurate results in detecting scoliosis.

The objective of this study is to find which YOLO algorithm is better between YOLOv3 and YOLOv4 in detecting scoliosis by (1) training both algorithms to automatically detect the vertebra and compute for the Cobb angle, (2) comparing the accuracy between the two by getting the percent error using the Cobb angle results, and (3) by comparing which algorithm saves more time using their execution time results.

This study will benefit the research regarding YOLOv3 and YOLOv4. It will show comparative data between the two object detection algorithms. An upgraded algorithm such as YOLOv4 can potentially improve the accuracy of detection. The time it will take to process the Cobb angle calculations will decrease, saving the doctor and patient’s time.

The scope of this study is to focus on comparing the two YOLO algorithms, namely, YOLOv3 and YOLOv4. These algorithms will be combined with OpenCV as the computer vision and machine learning library. Moreover, it will also be using the device in the research entitled, “Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCV”, which made use of a Raspberry Pi, a camera module, and an LCD screen to facilitate the algorithm training, Cobb angle calculations, picture taking of X-ray films, and the displaying of results.

II. METHODOLOGY

A. System Flowchart

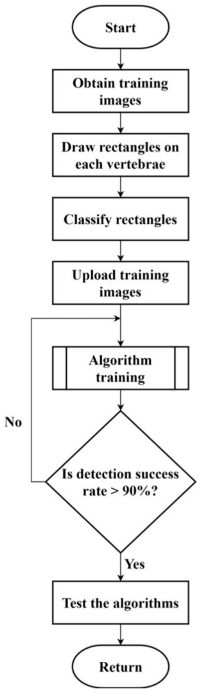

Fig. 1. System Flowchart

Fig. 1 represents how 400 training images of scoliosis X-rays are gathered to train both of the YOLO algorithms. The dataset was acquired from medical websites and SpineWeb, with several datasets available to the public. A program called LabelImg is used to create the bounding boxes on each vertebra in the X-ray images and classify them. The bounding boxes made using LabelImg are also called the Ground truth and will be compared with the predicted bounding boxes of the training algorithm using Intersection over Union (IoU). After that, the algorithm training for both YOLOv3 and YOLOv4 will start. The training will continue until the detection success rate of each algorithm is greater than 90 percent. Both weights will then be saved and tested using the X-rays captured using the camera.

B. Algorithm Training Flowchart

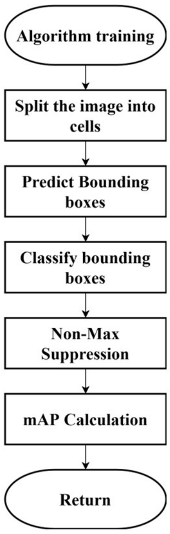

Fig. 2. Algorithm Training Flowchart

Fig. 2 is a simplified process of the training in YOLOv3 and YOLOv4. It splits the picture into a grid of cells then calculates the bounding boxes, which are the region of interest of the object with a confidence value. It then classifies which class of the bounding boxes. In this study, it is the vertebrae in the X-ray images. Since the algorithm produces multiple bounding boxes, this can result in numerous bounding boxes overlapping in the same vertebrae. That is why non-maximum suppression is utilized to reduce the detected boxes by getting rid of bounding boxes with low confidence. In addition to this, YOLO also uses Intersection over Union (IoU) to determine predicted bounding boxes with the same class that is overlapping and needs to be removed. After that, the mean Average Precision is calculated using IoU of the user labeled boxes and predicted boxes of the algorithm.

C. Training of YOLOv3 and YOLOv4

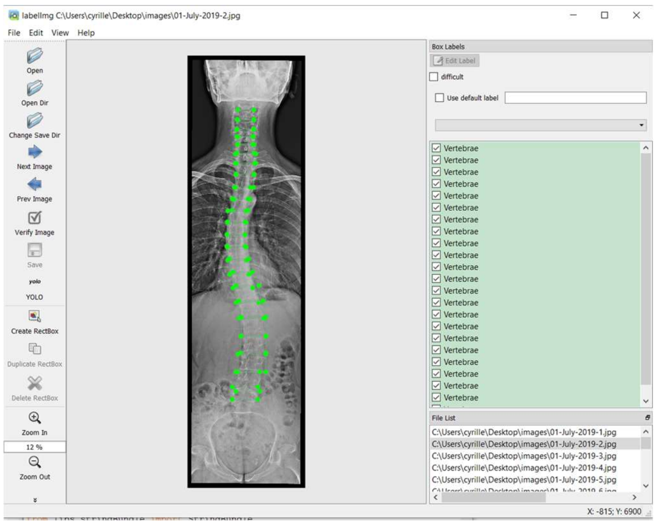

Fig. 3. Annotation of the Vertebrae

The training was conducted using Google Colab software, around 12GB RAM and 80GB storage. The training used for both YOLOv3 and YOLOv4 used the same datasets and took about 3000 iterations before it was stopped, in which the average loss of the training was less than 5%, and the mean Average Precision (mAP) at the IoU threshold of 0.50 was 72.17%. The images for the training were acquired from medical websites and SpineWeb, which have scoliosis X-ray images available publicly. Fig 3 shows the program used to annotate the X-ray images for the training and validation dataset.

The configuration for the training of both algorithms was computed using the following equations (1), (2), and (3).

$$Max\ batches\ (minimum\ 6000) = (number\ of\ classes) \times 2000 \quad (1)$$

$$Steps = \ (80\%\ of\ Max\ batches), (90\%\ of\ Max\ batches) \quad (2)$$

$$Filters = (Number\ of\ classes + 5) \times 3 \quad (3)$$

Since the number of classes needed to be identified in the study is only 1, the configuration settings for the training were Max_batches = 6000, steps = 4800,5400, and filters = 18.

D. *Testing of the Weights*

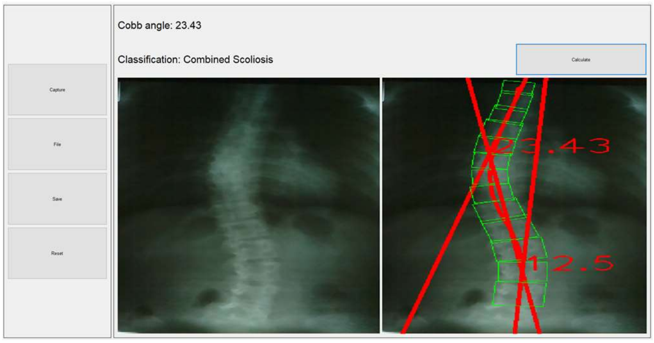

Fig. 4. Testing of YOLOv3

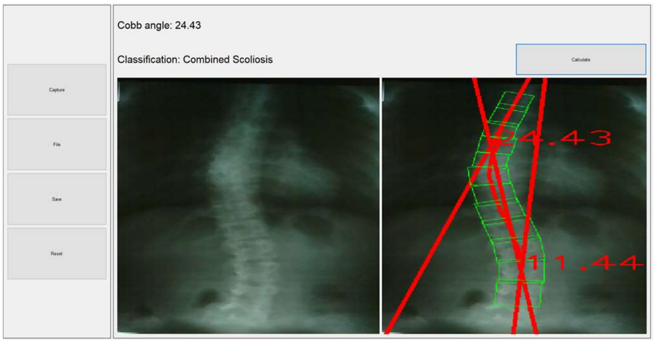

Fig. 5. Testing of YOLOv4

The validation data set was captured using the Raspberry Pi 4 device with 4GB RAM and 32GB storage. The camera attached to the Raspberry Pi was designed for the Raspberry Pi (5MP Omnivision 5647 Camera Module). The weights of both YOLOv3 and YOLOv4 were tested on the Raspberry Pi 4, running the application. YOLOv3 was run on Python 3.7 with OpenCV 3.4.3, while YOLOv4 was on Python 3.8 with OpenCV 4.4.0. In the application, the execution time (in seconds) of both weights was also tested using the timeit library of Python. Fig. 4 and Fig. 5 show an example test of the weights using the x-rays. In this test, both versions of YOLO could get an angle close to the doctor's measured value. When capturing the X-rays, the whole spine is captured and centered.

III. Results and Discussion

The test of both weights was conducted on the same X-ray images of the patients using the Raspberry Pi 4 device. The percentage error of YOLOv3 and YOLOv4 was calculated to determine how close the acquired values by both weights are to the actual value. Based on Table 1 and Table 2, YOLOv3 has an overall better result in determining the Cobb angle. There are also cases where YOLOv4 had closer values than YOLOv3; hence, the usage of YOLOv4 cannot entirely be dismissed since there is potential within higher iterations of training YOLOv4 can have better results.

TABLE I
Summary of Cobb Angle Tests

X-ray	Doctor Value (Actual)	YOLOv3	YOLOv4
1	16°	14.86°	8.62°
2	8°	9.45°	9.49°
3	11°	9.55°	11.4°
4	32°	35.25°	35.1°
5	53°	54.52°	50.25°
6	25°	23.43°	24.43°
7	22°	20.03°	28.79°
8	33°	34.15°	30.99°
9	22°	21.55°	22.53°
10	30°	29.78°	30.42°
11	20°	18.22°	23.03°

TABLE II
Comparison of Percentage Errors per X-ray

X-ray	YOLOv3 (% Error)	YOLOv4 (% Error)
1	7.125	46.125
2	18.125	18.625
3	13.182	3.636
4	10.156	9.688
5	2.868	5.189
6	6.28	2.28
7	8.955	30.864
8	3.485	6.091
9	2.045	2.409
10	0.733	1.4
11	8.9	15.15

$$\%\ Error = \frac{|Measured\ Value - Actual\ Value|}{Actual\ Value} \times 100\% \quad (4)$$

TABLE III
COMPARISON OF THE TEST RESULTS' EXECUTION TIME IN SECONDS

X-ray	YOLOv3 (seconds)	YOLOv4 (seconds)	% Difference
1	30.532	30.762	0.750
2	31.095	29.697	4.599
3	29.252	29.659	1.382
4	31.455	30.256	3.886
5	31.789	29.578	7.206
6	31.615	30.191	4.608
7	31.101	29.16	6.442
8	31.617	30.317	4.198
9	32.084	30.064	6.501
10	32.273	30.736	4.879
11	31.74	30.692	3.357
Average	31.323	30.101	3.979

$$\% \, Difference = \frac{|Value\ 1 - Value\ 2|}{\left(\frac{Value\ 1 + Value\ 2}{2}\right)} \times 100\% \tag{5}$$

In testing the execution time, it was tested in the Raspberry Pi 4 device using the same application in Table 1. The time was calculated using the timeit library of Python, calculating the time (seconds) it took for the application to calculate the Cobb angles of the X-ray images. Based on the results in Table 3, YOLOv4 had an overall faster execution time than YOLOv3, though the difference is slight, YOLOv4 still had faster execution than YOLOv3.

IV. CONCLUSION

The study was conducted to compare the performance of the two object detection algorithms, namely YOLOv3 and YOLOv4, on the device in the research entitled, "Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCV". Both algorithms were tested using the device, capturing the X-ray images of scoliosis patients and then computing for the Cobb angle. Based on the results, the YOLOv3 model had a higher measurement accuracy overall than the YOLOv4 model, having better results in 8 of the X-ray images. It should be noted that, although YOLOv3 had an overall better accuracy than YOLOv4, there are cases in the results where there was only a slight difference in the accuracy of the two algorithms. The test results for the execution time showed that YOLOv4 has a faster execution time than YOLOv3 with a 3.979% difference, making YOLOv4 the ideal choice if the speed of execution is more important.

V. RECOMMENDATION

The researchers recommend further training the algorithm in YOLOv4 to improve the accuracy of the Cobb angle computation. It is also recommended to gather more X-ray images from patients to increase the reliability of the results resulting in a more accurate sampling. The latest stable versions of YOLO advancing YOLOv3 and YOLOv4 are also recommended, such as YOLOv5 to upgrade the system. It is also recommended to test other object detection algorithms such as YOLOR, PP-YOLO, and Faster R-CNN, to see if the accuracy and speed of the system can further be increased.

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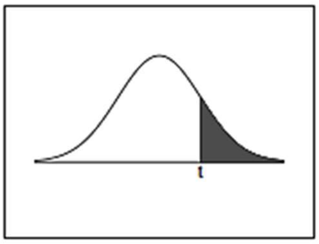
RECOMMENDATION FOR FURTHER STUDY

Improvements can be made by using other object algorithms under the family of YOLO such as YOLOv5, YOLOR, and PP-YOLO to know which of the following can provide better accuracy score, lightweight performance, and fast execution time to provide the best user experience for both the orthopedic doctor and the patient. It is also recommended to get a hand of clearer and updated X-ray films that are also less exposed—having little to no damage—since the quality of the X-rays also affects the results. Furthermore, it is recommended to train the algorithm multiple times and have training images greater than 400, which this study has used further to improve the accuracy and speed of the system.

APPENDICES

APPENDIX A

T-DISTRIBUTION TABLE



The shaded area is equal to α for $t = t_{\alpha}$.

df	$t_{.100}$	$t_{.050}$	$t_{.025}$	$t_{.010}$	$t_{.005}$
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
30	1.310	1.697	2.042	2.457	2.750
32	1.309	1.694	2.037	2.449	2.738
34	1.307	1.691	2.032	2.441	2.728
36	1.306	1.688	2.028	2.434	2.719
38	1.304	1.686	2.024	2.429	2.712
∞	1.282	1.645	1.960	2.326	2.576

APPENDIX B

SET-UP OF THE DEVICE

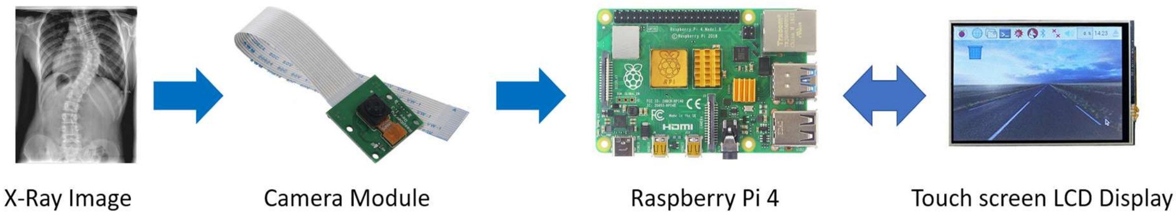


Figure B.1 System Setup

Figure B.1 shows the system set-up where the main hardware components are the camera module (5MP Omnivision 5647 Camera Module), Raspberry Pi 4, and a 3.5-inch LCD touchscreen display. The camera module is connected to the Raspberry Pi and is used to capture the X-ray images needed by the system. The coordinates of each vertebra of the spine will be tracked and are followed by the algorithm and training processes to determine the classification of scoliosis. The results and the application to operate the system will be displayed on the LCD.

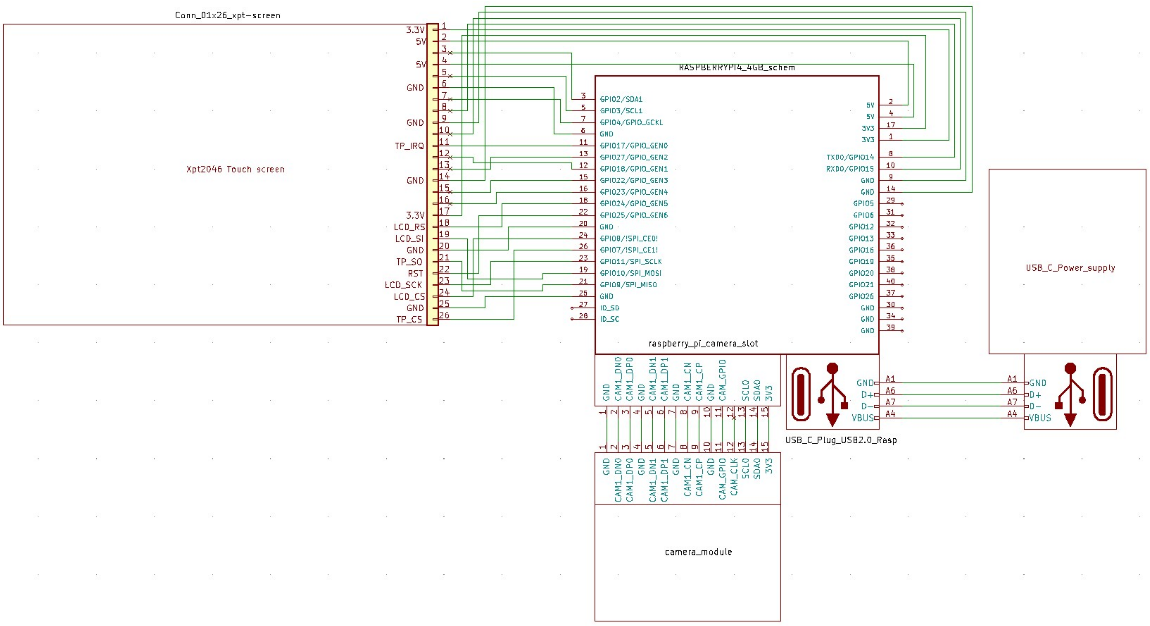


Figure B.2 Schematic Diagram

The schematic diagram shown in Figure B.2 represents how the LCD touch screen display and camera module are connected to the Raspberry Pi 4. The Raspberry Pi is powered via a USB-C cable connected to an adapter plugged in a 220V source electrical socket. The camera module is connected to the Raspberry Pi through its designated 15-pin ribbon slot for MIPI Camera Serial Interface (CSI), designed specifically for interfacing cameras. Meanwhile, the LCD occupies 26 pins on the Raspberry Pi for power, data transfer, display, and touchscreen capability.

APPENDIX C

EXPERIMENTAL SET-UP

Figure C.1 X-ray Film on Top of a Light Bed

The X-ray film is placed under a light source or over a light bed to show a clear image of the spinal curvature, which the Raspberry Pi camera module will capture. It's also essential to place the X-ray film on top of a flat surface to eliminate angles that may contribute to a faulty result.

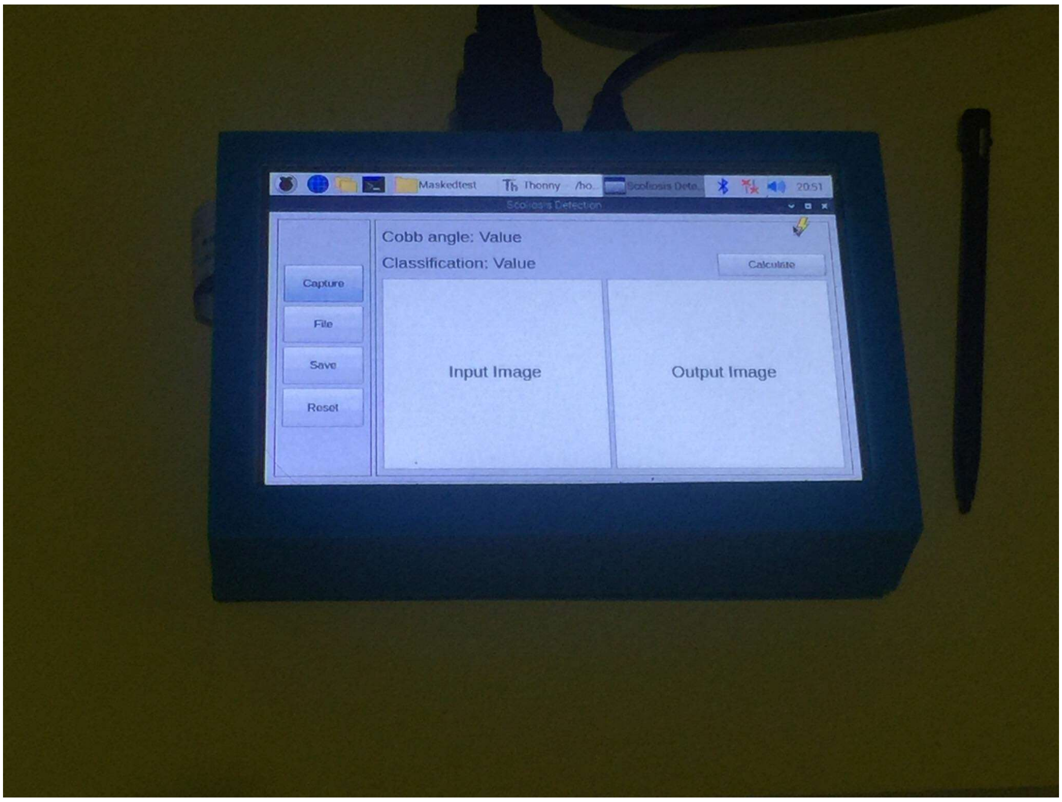


Figure C.2 GUI of the Device and Pen

The device user will open the application on the Raspberry Pi and click on the “Capture” button to start taking the X-ray picture. If there is already a photo available, the user can click on the “File” button instead and find the existing X-ray image to have its Cobb angle calculated.

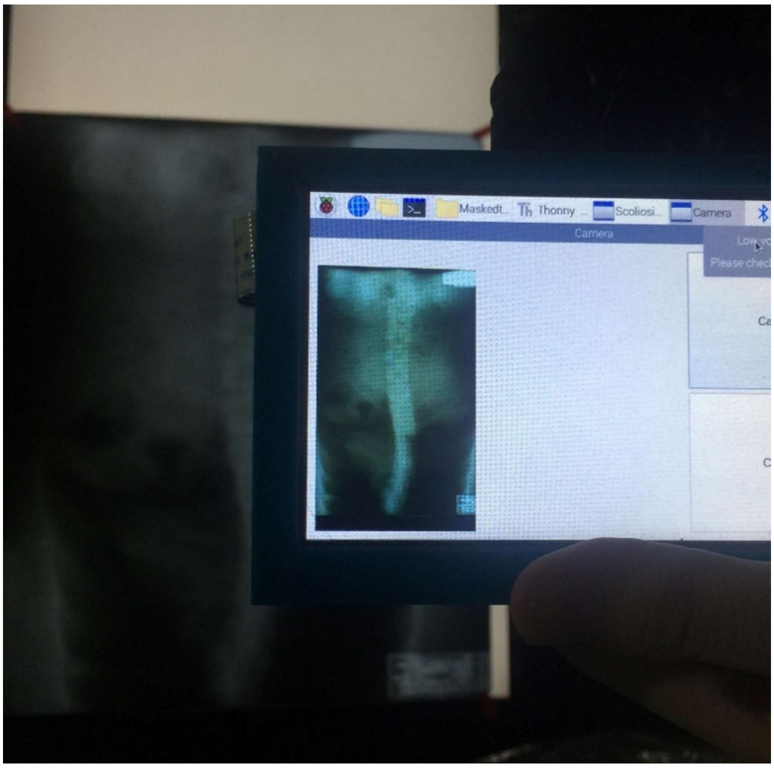


Figure C.3 Taking a Photo of the X-ray Film

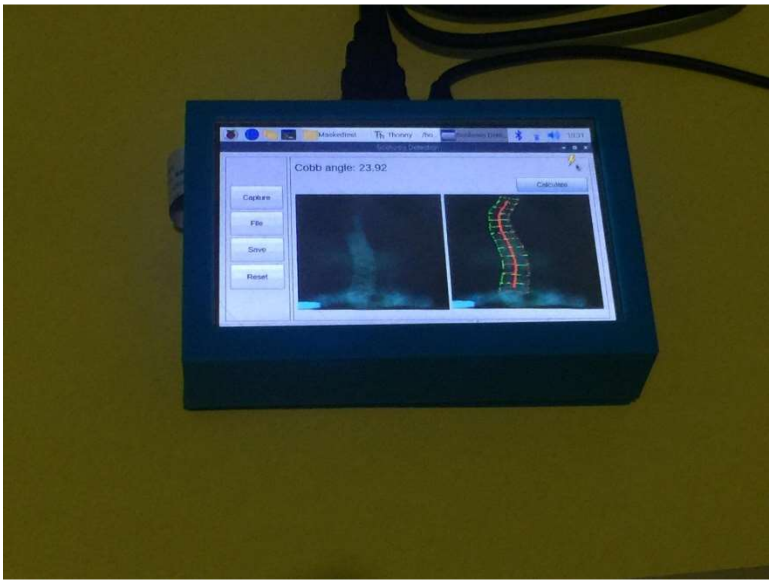


Figure C.4 Determination of the Vertebrae

The device user will now take a picture of the X-ray film, as shown in Figure C.3, making sure that the camera is perfectly aligned with the X-ray, avoiding unnecessary angles, and shaking to ensure that it won’t affect the quality of the photo taken. The image captured will undergo the process of the identification of the vertebrae, as shown in Figure C.4. The user will now press "Calculate" to compute for the Cobb angle and know the classification of scoliosis.

Figure C.5 Identification of the Upper and Lower Cobb Angles, and Classification

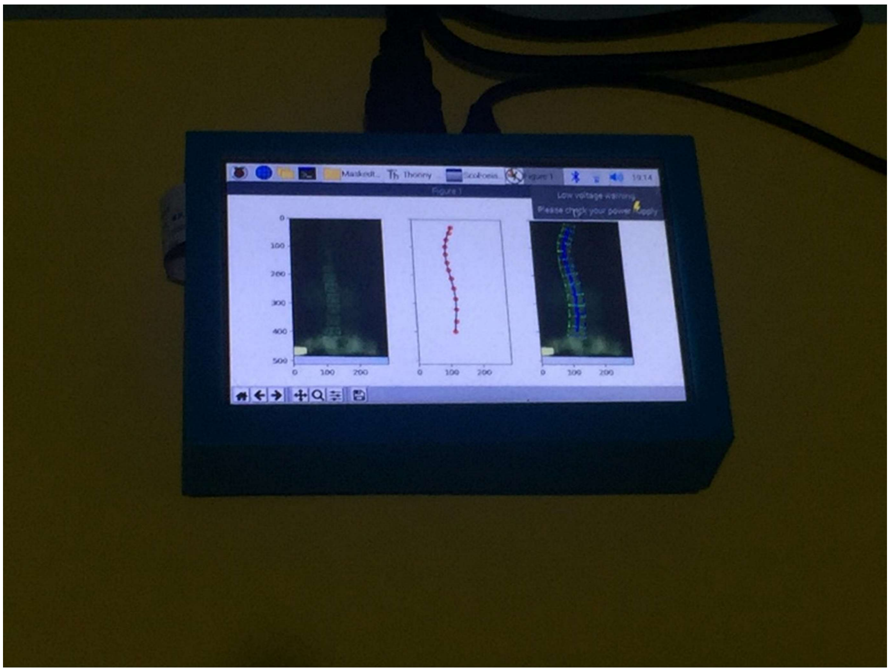


Figure C.6 Display of the Inflection Points

After calculation, the Cobb angle will now be shown on the screen, and the classification determined based on the upper and lower angle, as shown in Figure C.5. In Figure C.6, the user can see the original photo, the inflection points, and each identified vertebra in another window.

APPENDIX D

DOCTOR’S CONSULTATION PHOTO OP

Figure D.1, Dr. Mercado, using Pencil and Protractor Method

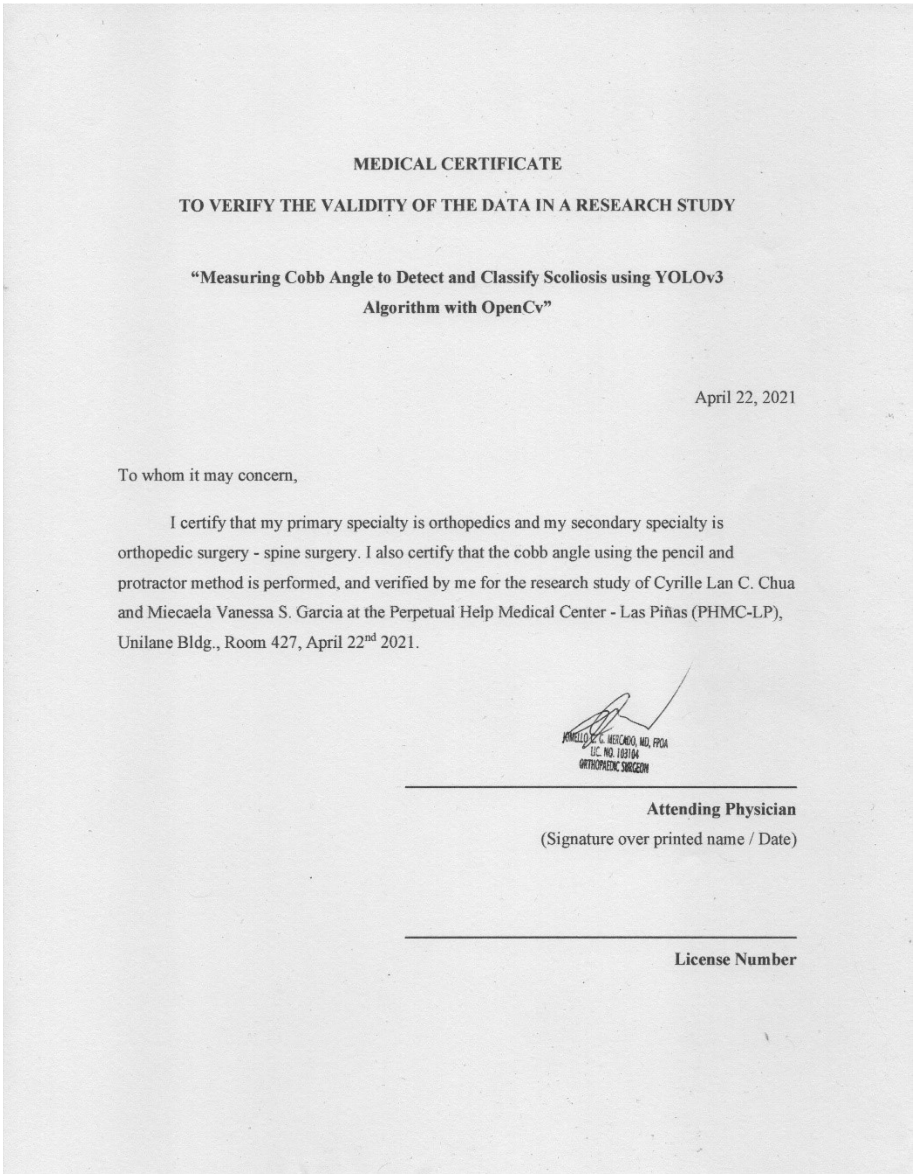
In Figure D.1, the orthopedic surgeon, Jomello Christian Garcia Mercado, MD, FPOA, uses the pencil and protractor method over a makeshift light bed—made by the researchers—to determine the Cobb angle per X-ray sample. His primary specialty if Orthopedics, and his secondary specialty is Orthopedic Surgery-Spine Surgery. His clinic location is U-MAB 427 at Perpetual Help Medical Center—Las Piñas (PHMC) and is available from 08:00 AM - 09:00 AM every Tuesday and Thursday.

Figure D.2 Photo with Dr. Mercado

In Figure D.2, Miecaela Vanessa S. Garcia, one of the researchers, took a photo with Dr. Mercado as proof of her visit to complete this research. It is also shown in the picture that health protocols were followed. Face masks and face shields were worn. Social distancing was also practiced.

APPENDIX E

MEDICAL CERTIFICATE



MEDICAL CERTIFICATE

TO VERIFY THE VALIDITY OF THE DATA IN A RESEARCH STUDY

"Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCv"

April 22, 2021

To whom it may concern,

I certify that my primary specialty is orthopedics and my secondary specialty is orthopedic surgery - spine surgery. I also certify that the cobb angle using the pencil and protractor method is performed, and verified by me for the research study of Cyrille Lan C. Chua and Miecaela Vanessa S. Garcia at the Perpetual Help Medical Center - Las Piñas (PHMC-LP), Unilane Bldg., Room 427, April 22nd 2021.

Attending Physician
(Signature over printed name / Date)

License Number

Figure E.1, Dr. Mercado, using Pencil and Protractor Method

In Figure E.1, the medical certificate is shown to verify that the consultation and the data were verified by a licensed orthopedic doctor, Dr. Mercado, last April 22, 2021.

APPENDIX F

LETTERS OF CONSENT

The photos below show evidence that the participating patients have given their consent to have their X-rays as data in this study.

<u>Patient Aliannah Taburo</u>

DATA PRIVACY CONSENT FORM
TO PARTICIPATE IN A RESEARCH STUDY

"Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCv"

PURPOSE

This research study is entitled, "Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCv," and is a requirement for the Thesis 1 course for the completion of the Bachelor of Science in Computer Engineering degree of Cyrille Lan C. Chua and Miecaela Vanessa S. Garcia.

The main objective of this research is to be able to detect and classify scoliosis based on the chest X-ray by (1) creating a device that can capture X-ray images, (2) training an algorithm to automatically detect the spine structure in X-ray images, (3) automatically compute for the Cobb angle based on the detected spine, and classify the scoliosis according to its angle classification whether thoracic, lumbar, thoraco-lumbar, or combined scoliosis, and by verifying the Cobb angle and classification using T-Test.

CONFIDENTIALITY

The researchers of Mapúa University as well as their faculty members recognize their responsibilities under the Republic Act No. 10173 (Act), also known as the Data Privacy Act of 2012, with respect to the data they collect, record, organize, update, use, consolidate or destruct from the volunteer patients for this study.

Furthermore, the information collected shall only be used solely for this research, and the researchers as well as the faculty involved shall not disclose patient's personal information without their consent and shall retain this information with no expiration date.

VOLUNTARY PARTICIPATION

Participation in this study is strictly voluntary. You understand that you are free to withdraw your consent to participate in this research at any time without prejudice. Refusal to participate will involve no penalty, and you may contact the following persons as stated below if you have questions or want to withdraw.

CONTACT PERSONS

Miecaela Garcia
mvsgarcia@mymail.mapua.edu.ph

Cyrille Chua
clcchua@mymail.mapua.edu.ph

CONSENT

I have read this form, understood its contents and consent to the processing of my personal data. I hereby affirm my right to be informed, object to processing, access and rectify, suspend or withdraw my personal data, and be indemnified in case of damages pursuant to the provisions of the Republic Act No. 10173 of the Philippines, Data Privacy Act of 2012 and its corresponding Implementing Rules and Regulations.

Complete Name of Patient: Aliannah Tuboro

Signature of Patient: ______________________

Date: December 28 2020

If below 18 years old,

Complete Name of Parent or Guardian: ____

Signature of Parent or Guardian: _______________________

Date: _______________

Patient Catherine Chua

DATA PRIVACY CONSENT FORM
TO PARTICIPATE IN A RESEARCH STUDY

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Complete Name of Patient: Catherine Chua `

Signature of Patient: ______________________________

Date: December 28 2020

If below 18 years old,

Complete Name of Parent or Guardian: ____

Signature of Parent or Guardian: _________________________

Date: ________________

Patient Ma. Johanna Elisha S. Bautista

DATA PRIVACY CONSENT FORM
TO PARTICIPATE IN A RESEARCH STUDY

"Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCv"

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Complete Name of Patient: Ma Johanna Elisha S Bautista

Signature of Patient: ______________________________

Date: 12/23/2020

If below 18 years old,

Complete Name of Parent or Guardian: ____

Signature of Parent or Guardian: _________________________

Date: ________________

<u>Patient Ma. Julienne Ella S. Bautista</u>

DATA PRIVACY CONSENT FORM
TO PARTICIPATE IN A RESEARCH STUDY

"Measuring Cobb Angle to Detect and Classify Scoliosis using YOLOv3 Algorithm with OpenCv"

PURPOSE

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Complete Name of Patient: Ma julienne ella s bautista

Signature of Patient: ________________________

Date: _______________

If below 18 years old,

Complete Name of Parent or Guardian: ____

Signature of Parent or Guardian: ________________________

Date: _______________

Patient Rizchelle Macaraig

DATA PRIVACY CONSENT FORM
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Complete Name of Patient: Rizchelle Macaraig

Signature of Patient: ________________________

Date: December 30 2020

If below 18 years old,

Complete Name of Parent or Guardian: ____

Signature of Parent or Guardian: ________________________

Date: ________________

Patient Ana Shane Velez

DATA PRIVACY CONSENT FORM
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PURPOSE

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Signature of Patient: ________________________

Date: December 30 2020

If below 18 years old,

Complete Name of Parent or Guardian: ____

Signature of Parent or Guardian: _________________________

Date: ________________