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

Cyrille Lan C. Chua[1], Miecaela Vanessa S. Garcia[2], Carlos C. Hortinela IV[3]

School of Electrical, Electronics, and Computer Engineering, Mapua Engineering
Muralla St., Intramuros, Manila 1002, Philippines

[1]clcchua@mymail.mapua.edu.ph

[2]mvsgarcia@mymail.mapua.edu.ph

[3]cchortinela@mapua.edu.ph

***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

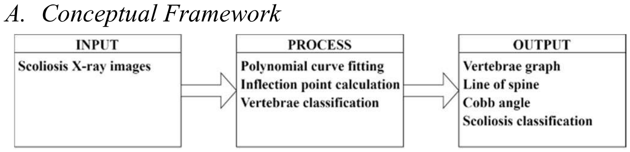

Fig. 1. Conceptual Framework

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

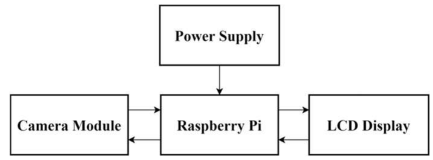

Fig. 2. Block Diagram

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.

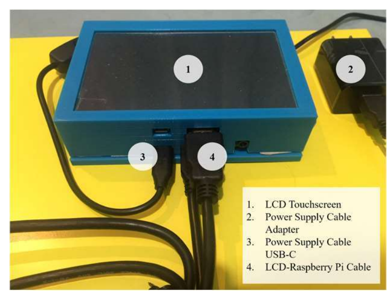

Fig. 3. Device Set-up Front View

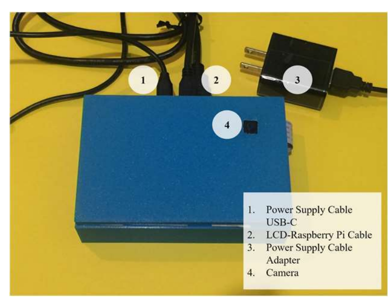

Fig. 4. Device Set-up Back View

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

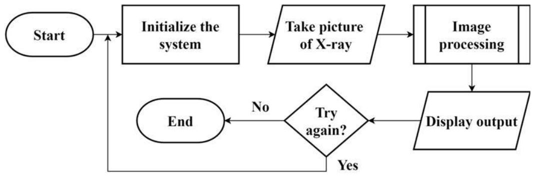

Fig. 5. Software Development Flowchart

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.

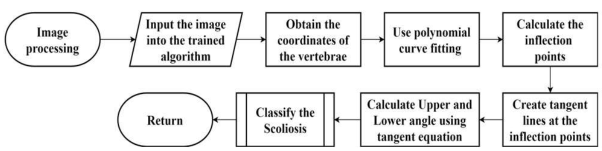

Fig. 6. Image Processing Flowchart

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.

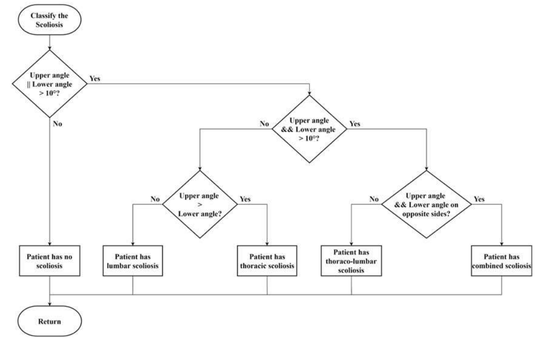

Fig. 7. Scoliosis Classification Subroutine

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.

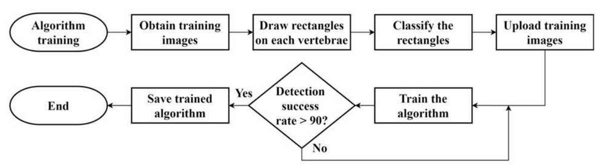

Fig. 8. Algorithm Training Flowchart

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.

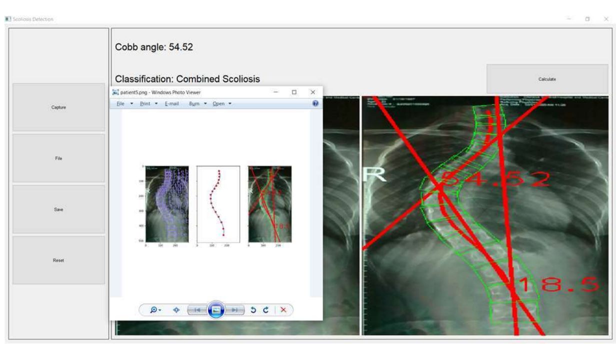

Fig. 10. The output of the system

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.

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

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.

REFERENCES

[1] F. R. G. Cruz, C. J. R. Santos, and L. A. Vea, (2019). "Classified Counting and Tracking of Local Vehicles in Manila Using Computer Vision," 2019 IEEE 11th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), Laoag, Philippines, pp. 1-5, DOI: 10.1109/HNICEM48295.2019.9072808.

[2] M. Doody, J. Lonstein, M. Stovall, D. Hacker, N. Luckyanov, and C. Land, (2000). "Breast cancer mortality after diagnostic radiography - Findings from the US Scoliosis Cohort Study," spine. 25. 2052-63, DOI: 10.1097/00007632-200008150-00009.

[3] M. Horng, C. Kuok, M. Fu, C. Lin, and Y. Sun, (2019). "Cobb Angle Measurement of Spine from X-Ray Images Using Convolutional Neural Network," Computational and Mathematical Methods in Medicine, pp 1-18, DOI: 10.1155/2019/6357171.

[4] C. Hortinela, et al. (2021), "Milled Rice Grain Grading using Raspberry Pi with Image Processing and Support Vector Machines with Adaptive Boosting," 2020 IEEE 12th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM). DOI: 10.1109/hnicem51456.2020.9400102.

[5] S. Jeong, S. Shin, J. An, and S. Chung, (2013). "3D modeling of musculoskeletal Cobb's angles," 2013 6th International Conference on Biomedical Engineering and Informatics, Hangzhou, pp. 393-397, DOI: 10.1109/BMEI.2013.6746970.

[6] B. A. Kusuma, (2017). "Determination of spinal curvature from scoliosis X-ray images using K-means and curve fitting for early detection of scoliosis disease," 2017 2nd International Conference on Information Technology, Information Systems and Electrical Engineering (ICITISEE), Yogyakarta, pp. 159-164, DOI: 10.1109/ICITISEE.2017.8285486.

[7] A. R. Levy, M. S. Goldberg, N. E. Mayo et al. (1996). "Reducing the lifetime risk of cancer from spinal radiographs among people with adolescent idiopathic scoliosis," spine, vol. 21, no. 13, pp. 1540-1547, DOI: 10.1097/00007632-199607010-00011.

[8] C. O. Manlises, J. M. Martinez, J. L. Belenzo, C. K. Perez, and M. K. T. A. Postrero, (2015). "Real-time integrated CCTV using face and pedestrian detection image processing algorithm for automatic traffic light transitions," 2015 International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM), Cebu City, pp. 1-4, DOI: 10.1109/HNICEM.2015.7393205.

[9] P. Maolanon and K. Sukvichai, (2018) "Development of a Wearable Household Objects Finder and Localizer Device Using CNNs on Raspberry Pi 3," 2018 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE), Chonburi, Thailand, pp. 25-28, DOI: 10.1109/WIECON-ECE.2018.8782924.

[10] D. Padilla, R. Pajes and J. De Guzman, (2020), "Detection of Corn Leaf Diseases Using Convolutional Neural Network With OpenMP Implementation," 2020 IEEE 12th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), 2020. DOI: 10.1109/hnicem51456.2020.9400004.

[11] A. N. Yumang, C. C. Paglinawan, L. C. M. Andrada, E. C. Garcia, and J. M. F. Hernandez, (2018). "Optimization of Vehicle Speed Calculation on

Raspberry Pi Using Sparse Random Projection," 2018 IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology, Communication, and Control, Environment and Management (HNICEM), Baguio City, Philippines, pp. 1-6, DOI: 10.1109/HNICEM.2018.8666325.

[12] B. Prisacariu, B. Dimitriu, and E. Lungu, (2017). "Scoliosis risk assessment in children with pelvic asymmetry - a simple screening test based on gluteal area asymmetry," 2017 E-Health and Bioengineering Conference (EHB). DOI: 10.1109/ehb.2017.7995534.

[13] A. Safari, H. Parsaei, A. Zamani, and B. Pourabbas, (2019). "A Semi-Automatic Algorithm for Estimating Cobb Angle," 9. pp. 317-326, DOI: 10.31661/jbpe.v9i3Jun.730.

[14] L. Seoud, J. Dansereau, H. Labelle, and F. Cheriet, (2013). "Noninvasive Clinical Assessment of Trunk Deformities Associated With Scoliosis," in IEEE Journal of Biomedical and Health Informatics, vol. 17, no. 2, pp. 392-401, DOI: 10.1109/TITB.2012.2222425.

[15] P. Sismananda, M. Abdurohman, and A. G. Putrada, (2020). "Performance Comparison of Yolo-Lite and YoloV3 Using Raspberry Pi and MotionEyeOS," 2020 8th International Conference on Information and Communication Technology (ICoICT), Yogyakarta, Indonesia, 2020, pp. 1-7, DOI: 10.1109/ICoICT49345.2020.9166199.

[16] J. Villaverde, Y. Sarmiento, and M. Agbulosm, (2021). "Identification of Leaf Blast and Brown Spot Diseases on Rice Leaf with YOLO Algorithm," 2021 IEEE 7th International Conference on Control Science and Systems Engineering (ICCSSE). DOI: 10.1109/iccsse52761.2021.9545153.

[17] J. Villaverde, L. Tan, and S. De Guzman, (2021). "Social Distancing Violation Monitoring Using YOLO for Human Detection," 2021 IEEE 7th International Conference on Control Science and Systems Engineering (ICCSSE). DOI: 10.1109/iccsse52761.2021.9545098.

[18] S.K. Wardani, R. Sigit, Setiawardhana, S.M.S. Putri, and D. Yunitasari, (2018). "Measurement of Spinal Curvature for Scoliosis Classification," 2018 International Seminar on Application for Technology of Information and Communication, Semarang", pp. 266-270, DOI: 10.1109/ISEMANTIC.2018.8549787.

[19] H. Wu, C. Bailey, P. Rasoulinejad, and S. Li, (2017). "Automatic Landmark Estimation for Adolescent Idiopathic Scoliosis Assessment Using BoostNet," pp.1-9, DOI: 10.1007/978-3-319-66182-7_15.

[20] W. Wu, and Q. Li, (2020). "Machine vision inspection of electrical connectors based on improved Yolo v3," in IEEE Access, pp. 1-1, DOI: 10.1109/ACCESS.2020.3022405.

[21] D. A. Padilla, A. M. Hubalde, and D. A. C. Santos, (2021) "A YOLO-Based Approach for Aedes Aegypti Larvae Classification and Detection," 2021 6th International Conference on Image, Vision, and Computing (ICIVC), pp. 161-167, DOI: 10.1109/ICIVC52351.2021.9527017.