SCOLIOVIS: Automated Cobb Angle Measurement on Anterior-Posterior Spine X-Rays using Multi-Instance Keypoint Detection with Keypoint RCNN

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In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science in Computer Science

by

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March 2023

Approval Sheet

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March 2023

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Abstract

The study proposes an automated tool called ScolioVis, which uses computer vision and machine learning techniques to extract the Cobb Angle from anterior-posterior Spine x-ray images. The tool employs the Keypoint RCNN model for object detection and keypoint estimation trained on the SpineWeb Dataset 16 and achieved an accuracy of 93% AP at IoU=0.50 on object detections and 57% AP at IoU=0.50 on keypoint detections. Additionally, the system was evaluated using the ISO/IEC 25010 standard, and high quality and effectiveness in meeting user needs, with all eight characteristics assessed being rated as "Very Good". The proposed system has a high potential for improving scoliosis diagnosis and treatment by reducing the manual labor time and errors associated with traditional manual methods.

Table of Contents

List of Figures

List of Tables

List of Appendices

CHAPTER 1 INTRODUCTION TO THE STUDY

1.1 Background of the Study

Scoliosis is a disorder of the spine in which it is rotated and/or bent away from the regular shape (Baaj, 2017). It is a three-dimensional spinal condition regarded as the most common pediatric musculoskeletal disorder (Karpiel, 2021). According to Wu et al (2019), 2.5% of the general population suffer from adolescent idiopathic scoliosis. This deformation is examined through an x-ray scan of the body (Enríquez, 2014). The spinal curve’s severity is then determined based on the value of the Cobb Angle (Preston, 2016). This angle is measured with a ruler and a protractor by locating the apex of the curve and determining the top and bottom vertebrae with the most tilt on both ends of the curve (Asher, 2020). It is currently still being measured manually with the use of anterior-posterior and lateral X-ray views (Zhang, 2022).

Computer Vision is a field concerned with making computers capable of understanding visual data such as videos and images (Brownlee, 2019b). Computer vision can provide multiple benefits to the medical industry ranging from better patient identification to more efficient imaging analysis as well as other purposes (Goldsmith, 2021). One notable ability of computer vision systems is object detection (Verschae & Ruiz-del-Solar, 2015). Object detection, as a task, is when objects are identified and then located within images and surrounded with a bounding box (Brownlee, 2019a). This particular method can be useful in detecting a vertebra within an x-ray of a spinal column. After which, estimated keypoints within each vertebra can be used as data to determine the cobb angle and perform a proper diagnosis.

According to Common Objects in Context (2021), the task of simultaneous object detection and keypoint estimation is relatively new. For simplicity, the task is referred to as keypoint detection, and the prediction algorithm as the keypoint detector. This study proposes the use of the Keypoint RCNN model that is notoriously used for detecting human instances and performing Pose Estimation, only this time, applied to vertebrae instances to perform keypoint detection on the four corner points of the vertebra.

1.2 Theoretical Framework

Locating these vertebrae would require understanding the different sections of the spine.

According to Horng, et al. (2019), in order to perform spine curvature quantification or cobb angle measurement, the following processes must first be done on the X-ray spinal image: isolate the spine region, detect the vertebrae, and finally perform vertebrae segmentation. According to Kayalioglu (2009), all vertebrates have a vertebral column that acts as the central axis of the skeleton; in human beings there are 33 vertebrae, from top to bottom there are 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 caudal vertebrae. Automatic cobb angle measurement can be done by locating the vertebra, and then performing landmark estimation methods on it to find the four corners (Khanal, et al, 2019).

Object detection models like YOLO and R-CNN are evaluated by calculating their mean average precision (Gad, 2021). A standard tool for determining the overlap between two dataset is intersection-over-union or IOU(Moore, 2020). IOU can be determined by the area of overlap divided by the area of union (Rosebrock, 2016). Another standard metric used in machine learning is dice similarity coefficient which can be determined through: $2 * |X \cap Y| / (|X| + |Y|)$; wherein X and Y are the two segmentation sets (Bell, et al, 2021).

1.3 Objectives of the Study

The study aimed to develop a system for automated cobb angle measurement of anterior-posterior spinal x-ray images for scoliosis using computer vision.

It, specifically, aimed to:

1. Develop and train a Keypoint RCNN model to perform multi-instance keypoint detection on spine x-ray images.
2. Evaluate the AP^{IOU} and AP^{OKS} performances of the object detection and keypoint detection respectively.
3. Determine the symmetric mean average percent error (SMAPE) of the cobb angle measurement algorithm;
4. Create and deploy a web app for the system;
5. Perform usability testing on the system using ISO 25010 Software Quality Standard;

1.4 Significance of the Study

The study would be beneficial to the following:

X-ray specialists.

The algorithm can help speed up their examination process by making the measurement automatic.

Occupational therapists, physical therapists, and scoliosis patients.

They can make use of ScolioVis when it comes to diagnosis, and deciding the therapy plan in case measurements were not provided in the X-ray scan.

Brace manufacturers.

Brace manufacturing is also dependent on the Cobb Angle as well as the X-ray scan thus making ScolioVis valuable to brace manufacturers as well.

Future researchers.

The data analysis and results of the study may be valuable to future researchers that also wish to conduct a study in computer vision and medical imagery.

1.5 Definition of Terms

For better understanding, the following terms were defined conceptually and operationally:

System.

This term is used in the study to refer to the "ScolioVis" system as a whole with the frontend interface that the user interacts with as well as the backend component that houses both the model and the algorithm.

Model.

A model, in machine learning, is a structure designed to solve the problem that it was made to address (Murphy, 2019).

In the study, this term is used to refer to the model component in the system that is trained and tested to analyze spine images. The output of the model component is used by the algorithm component of the study. In the study, the model detects the vertebrae and then predicts the keypoints within each individual vertebrae which is then used by the measurement algorithm to retrieve the angle.

Keypoint Detection.

According to X. Wu, et al (2020), keypoint detection can either be done with corner-based, or center-based methods. Corner-based involves predicting bounding boxes based on pairs of corners that are learned from a feature map. Center-based methods involve predicting the center of objects within a feature map, and with that, the width and height of each object are regressed. In various related literature, it may also be called the following names: Landmark Detection, Landmark Estimation, or Pose Estimation.

In the study, Keypoint Detection refers to Multi-instance keypoint detection, the computer vision task done to accomplish the detection of individual vertebrae as well as the 4 corresponding keypoints of that vertebra.

Algorithm.

An algorithm is defined as a set of instructions that are used to perform a certain task (Downey, 2022).

In the study, this term refers to the Cobb Angle Measurement Algorithm that takes the keypoints as input to output the three Cobb angle values (PT, MT, TL/L).

Scoliosis.

According to Cleveland Clinic (2019), Scoliosis refers to when the spine curves away from the normal alignment. In the study, Scoliosis is the medical condition that is being described quantitatively via the Cobb Angle.

Idiopathic Scoliosis.

Idiopathic scoliosis means that the scoliosis that is diagnosed has no specific evidence that can pin its development to any certain cause (Trobisch et al., 2010). In the study, it refers to the common type of scoliosis that is assessed.

Cobb Angle.

Cobb Angle is the standard measurement of Scoliosis coined by John Robert Cobb (Asher, 2020). In the study, it is the value that the Algorithm measures.

Apex.

The apex is defined as the point at which a curve is at its sharpest (Merriam-Webster, n.d). In the study, it refers to the farthest point of the curve in scoliosis.

X-ray.

An X-ray is a type of radiation that is used for making biomedical imagery showing a person's bones and other structures within the body (NIBIB, 2016). The study specifically Anterior-Posterior view X-ray images as data for the Algorithm.

Computer Vision.

Computer Vision is a field of artificial intelligence that allows a computer to perceive and understand visual inputs in a certain way (Marr, 2021). The computer vision method implemented in the study is multi-instance keypoint detection.

Vertebrae/Vertebra.

The vertebrae are a series of bones in the spine that are labeled based on their position in the column (Britannica, 2020). The study makes use of 17 vertebrae on the spinal column, 12 from the thoracic region and 5 from the lumbar region.

Thoracic vertebrae.

The thoracic spine is the middle section of the spine that comes after the neck and ends where the lower back starts (Eidelson, 2020). In the study, these are the discs labeled T1 up to T12.

Lumbar vertebrae.

This refers to the five remaining vertebrae below the thoracic vertebrae (Hacking & Wong, 2015). In the study, these are the vertebrae L1 to L5.

Scoliosis Curve Types.

Kim, et al (2013) defines the scoliosis curve type based on its Lenke Classification as follows:

Proximal Thoracic Curve (PT).

The curve is proximal thoracic if the apex is located in T3, T4, or T5.

Main Thoracic Curve (MT).

The curve is in the main thoracic if the apex is located between T6 and T12.

Thoracolumbar/Lumbar Curve (TL/L).

Lastly, if the apex is located between T12 and L1, then it is in the Thoracolumbar region, while if it is between L1-L2 and L4, then it is in the Lumbar region.

The study abbreviates the three as PT, MT, and TL/L respectively.

1.6 Delimitation of the Study

The study only makes use of anterior-posterior spinal X-rays and not lateral spinal X-rays.

The study focused on the development of the machine learning model and a cobb angle measurement algorithm which were both implemented into a web app and functioned as a single system.

The model accomplishes the task of multi-instance keypoint detection using a modified Keypoint RCNN model limited to the performance metrics based on COCO Keypoint Evaluation metrics.

The cobb angle measurement algorithm is limited to extracting the PT, MT, and TL/L, and the evaluation of performance is only limited to metrics provided on AASCE 2019 Grand Challenge.

The cobb angle is the standard measurement for scoliosis (Asher, 2020), there are other assessments to diagnose scoliosis like the Lenke classification, which are not within the scope of the study.

The study has no control over how the radiograph was taken or how the patient was positioned during the time of taking it.

The study is limited to the examination of the specific automatic Cobb angle measurement application by the authors, and does not encompass a comparison with the semi-automatic medical-grade equipment utilized by radiologists. This exclusion is due to confidentiality concerns as articulated by the radiologist consultants and cannot be disclosed in the study.

The study utilizes Python as the exclusive programming language in developing the model along with Pytorch, OpenCV, and FastAPI. NextJS, React, Tailwind, and Typescript will be used to develop the frontend of the program.

CHAPTER 2 REVIEW OF RELATED STUDIES

2.1 Different Types of Scoliosis

There are different classifications of scoliosis which are based on the cause that lead to the deformation of the spine, these are: congenital, neuromuscular, syndrome-related, idiopathic and spinal curvature due to secondary reasons. The most common form that general practitioners come in contact with is idiopathic (Janicki & Alman , 2007).

For idiopathic scoliosis, it can be classified based on when it was first recognized, these categories are infantile, juvenile, adolescent, and adult (Trobisch et al., 2010). The study will mainly focus on adolescent idiopathic scoliosis.

2.2 History of Scoliosis Diagnosis Techniques

Scoliosis was measured and diagnosed through a multitude of ways including inclinometers, pantographs, and plaster casts (Stokes, 1989). With the use of spinal radiograph, the lateral angle of a curvature of the spine is measured and if it is greater than 10 degrees it is scoliosis (Karpiel, 2021). This minimum angle measure is also the same standard used by the specialist consulted in the current study for determining scoliosis in her patients.

2.3 Pre-Existing Cobb Angle Measurement Techniques

In regards to Cobb angle measurement, there have been a few different techniques in the past that other studies have implemented in their work.

As noted by H. Wu, et al (2017), several mathematical models have already been proposed for measuring the Cobb Angle. These include Active Contour Model, Customized Filter, and Charged particle models. However, they also note that these models are computationally expensive and prone to errors.

In a later study (Horng et al., 2019), researchers used a method for extracting only one cobb angle value from an anterior-posterior spine image, without consideration for the PT, MT, and TL/L. After the model defines the upper and lower borders of the vertebrae, the spine curvature can be calculated using the formula in Figure 1.

$$\varphi = \max\left\{\left|\tan^{-1}\left(\frac{m_i - m_j}{1 + m_i \times m_j}\right)\right|\right\},$$
$$(i, j) \in \{(a, b) \mid a \in \mathbb{N}, b \in \mathbb{N}, b - a \geq 2 \text{ and } b \leq N\},$$

Figure 1. *Formula for Calculating Spine Curvature in a study by Horng et al. (2019)*

As for more recent techniques, Maguire (2020) created an automatic scoliosis assessment tool that takes in a spine X-ray image and segments it using a model. The tool proposed novel methods to determine the slopes of each endplate of the segmented vertebrae. This allows for rapid and robust automatic measurement of the PT, MT, and TL/L Cobb angles.

Several studies made use of symmetric mean average percent error or SMAPE to determine the accuracy of their cobb angle measurement algorithms. Three methods known as Landmark Net, Angle Net, and AEC-NET, respectively, achieved the following SMAPEs: 38.87, 23.91, and 23.59 (Chen et al., 2019). A separate study that used the previous one as reference achieved a value of 21.71 which is an even lower symmetric mean average percent error (Lin et al., 2019).

2.4 Agile Software Development Life Cycle In Machine Learning Projects

According to Singla, et al. (2018), the Agile software development life cycle has become a de facto standard for many new projects at many big companies. It has been very popular because of its advantages in flexibility and rapid prototyping cycles.

In a more recent study on the Agile Development of Machine Learning Models in Healthcare (Jackson, et al.

2018), it's recommended to incorporate a formal agile tracking tool for tracking "backlogs" to keep track of upcoming tasks, as not every feature or user story will be complete before a product release. It's also recommended to investigate and implement as it's more important in data science problems to allow sufficient time for problem understanding, and thereby clearly define the ideal boundaries of the prediction pipeline. Lastly, it's also recommended to release in increments which ensures that realistic deadlines are formed because the model is developed in small steps. This also allows time for independent feedback regarding the codebase and for completion of remaining backlog tasks, which could improve the overall performance and quality in later releases.

2.5 Evaluating Software Quality Standards

The quality model defined in ISO/IEC 25010 is widely used in the software industry for evaluating the quality of a product. The model categorizes product quality into eight characteristics and corresponding sub-characteristics (ISO/IEC 25010, 2011). These characteristics are functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability and portability. Each of these characteristics is critical for ensuring that the product meets the needs of its stakeholders and provides value.

Functional suitability, performance efficiency, and compatibility are concerned with the product's functionality, performance and compatibility with other products. Usability evaluates the user experience, taking into account factors such as learnability, operability, and accessibility. Reliability assesses the product's ability to perform as intended over time. Security is concerned with the protection of information and data. Maintainability is the degree of effectiveness and efficiency with which the product can be modified and improved. Portability is the degree to which a product can be transferred from one environment to another without modification.

CHAPTER 3 RESEARCH DESIGN AND METHODOLOGY

3.1 Description of the Study

The study developed a computer vision algorithm named ScolioVis with the purpose of automating the Cobb angle measurement process. The methods of the study are divided into 3 phases, Preparation, Implementation, and Evaluation.

In the preparation phase of the study, the researchers consulted with a specialist with experience in Cobb Angle measurement, and acquired and explored the necessary dataset.

In the implementation phase of the study, the processes involved are creating the learning models, designing the measurement algorithm, and developing the web application to deploy the model and the algorithm into.

In the evaluation phase of the study, the researchers tackled the specific objectives which are to evaluate the model precision and cobb angle measurement algorithm accuracy by collecting the appropriate data needed for each.

3.2 Methods and Proposed Enhancements

3.2.1 Preparation

Consulting Specialist

The study requires consultation with a specialist in radiographs, specifically, one experienced in handling Cobb angles. The chosen consultant was Dr. Jocelyn F. Villanueva who is a licensed radiologist. In the consultation, she demonstrates the two methods in which she performs cobb angle measurement: manual measurement, and using a semi-automatic radiologist tool in her computer.

Dataset Acquisition and Exploration

The dataset was retrieved through sending a request to SpineWeb for their Dataset 16. It consists of 609 spinal anterior-posterior x-ray images with keypoints used to calculate the Cobb Angle (H. Wu et al., 2017). In previous studies, this dataset was used for adolescent idiopathic scoliosis assessment. The dataset is split into 481 in the training set and 128 in the test set. Aside from the images, the specific values that the dataset contains are file names, 136 columns of keypoints, and 3 columns of Cobb angles. A sample of the images being used is showcased in Figure 2.

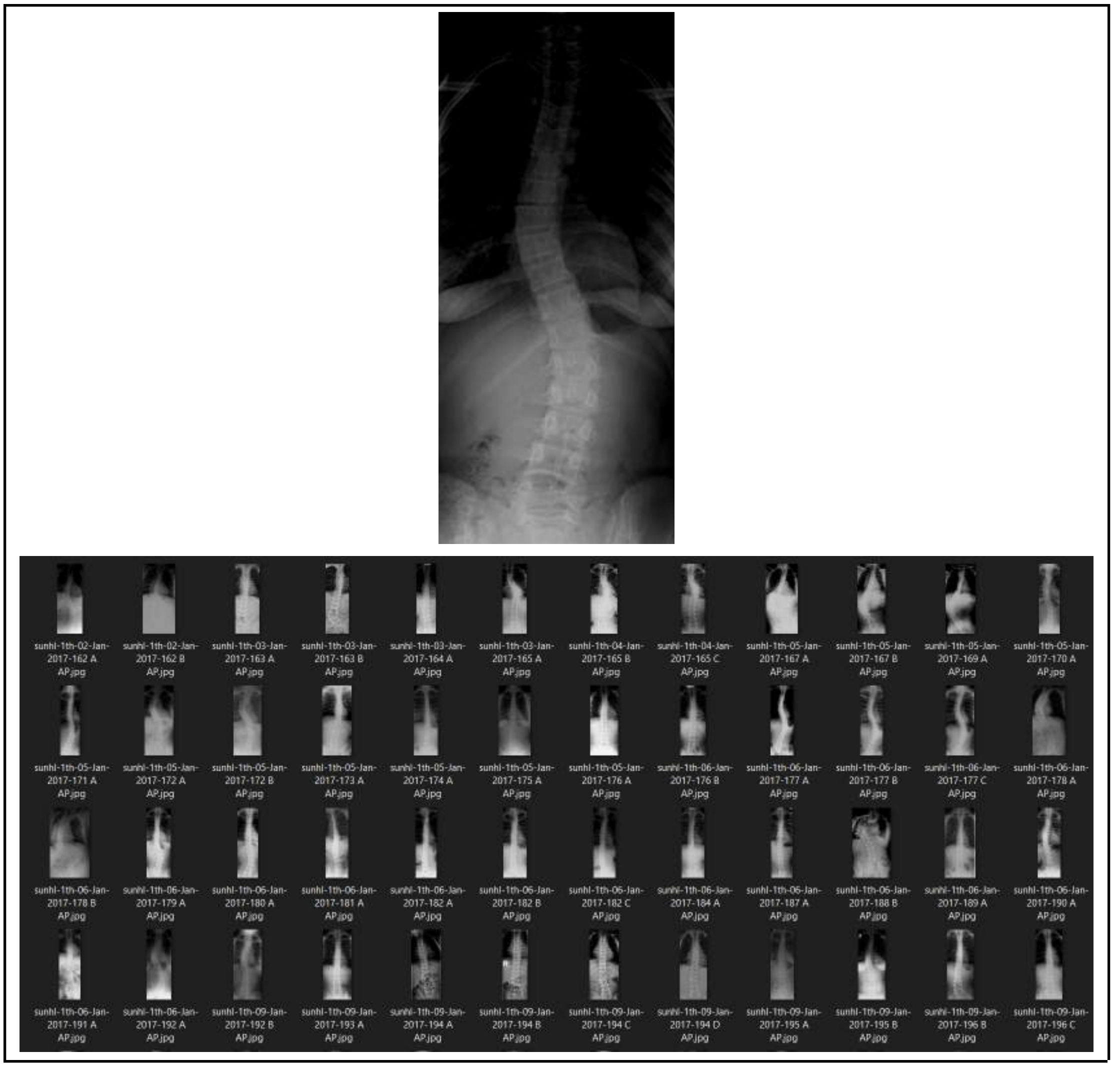

Figure 2. X-ray Images retrieved from the Dataset

3.2.2 Implementation

Keypoint RCNN Model Training and Testing

The model was developed using Python as the primary language with the use of libraries like Pytorch and OpenCV. A Jupyter Colab notebook was used as the development environment for data preprocessing, model training, and testing.

The input to the model is expected to be a list of tensors, each of shape [C, H, W], one tensor for each image, and should be in 0-1 range. Different images can have different sizes.

During training, the model expects both the input tensors, as well as the targets, which is a list of dictionaries containing boxes, labels, and keypoints.

During inference, the model requires only the input tensors, and returns the post-processed predictions as a list of dictionaries containing tensors for each image.

The fields of the dictionary are as follows: boxes, labels, scores, and keypoints.

The model is modified to predict 4 keypoints, referring to the corner points of each vertebra instance detected. It was trained for 50 epochs.

Designing the Cobb Angle Measurement Algorithm

According to Greiner (2002), Cobb angle is the most widely used measurement for quantifying spine curvature. The Cobb Angles are calculated using these keypoints retrieved from the model.

Locating the midpoints and midlines

The keypoints of each vertebra are used to retrieve the two midpoints that make up their midlines. For clarity's sake, the upper keypoints are point 1 and point 2 while the lower keypoints are point 3 and point 4. Each of these keypoints are made of their x and y values.

Their midpoints are determined by the formula in Figure 3.

$$first\ midpoint\ =\ ((x_1 + x_3)/2,\ (y_1 + y_3)/2);$$

$$second\ midpoint\ =\ ((x_2 + x_4)/2,\ (y_2 + y_4)/2);$$

Figure 3. *Formula for first and second midpoint*

The horizontal and vertical distance between the two midpoints can be determined using the formula in figure 4, wherein the x and y represent their respective coordinates.

$$distance_x,\ distance_y\ =\ (x_1 - x_0,\ y_1 - y_0);$$

Figure 4. *Formula for horizontal and vertical distance*

These values are then used to determine the length of each midline using the pythagorean theorem as seen in Figure 5.

$$length\ =\ \sqrt{(distance_x)^2 +\ (distance_y)^2}$$

Figure 5. Formula for the length of the midline

Determining the Cobb Angle

Midline lengths and the difference of horizontal and vertical distance of two vertebrae is used to determine the cobb angle using the formula in Figure 6.

$$\theta = ((\,arccos(\frac{(distance_{x0}*distance_{x1})+(distance_{y0}*distance_{y1})}{length_0 * length_1})) \times 180/\pi)$$

Figure 6. *Formula for determining the cobb angle*

This formula is then applied to every possible vertebra combination and the highest combination is considered the primary scoliosis curve.

Using the method of H. Wu, et al (2017), the location of these vertebrae are used to determine the shape of the spine which is then used to locate remaining two minor curves using the same processes as the first.

Web Application Development and Model Deployment

The frontend web application was developed using Typescript as the primary language with NextJS and React as the frontend framework and Tailwind for styling. The backend was developed using Python as the primary language with Pytorch for loading the model and FastAPI as the backend framework.

3.2.3 Evaluation

Determining Landmark Estimation Model Performance

The image segmentation model was evaluated based on its Precision and Recall, Jaccard's Index(IOU), and DSC.

As stated by Tiu (2019), IOU and DSC can be determined by the formula in figure 7.

$IOU = A(o)/A(u)$

$DSC = (2 * A(o))/P;$

Figure 7. Formula for IOU and DSC

wherein, DSC = Dice Similarity Coefficient, A(o) = Area of Overlap, A(u) = Area of Union, and P = Total Number of Pixels.

The Precision and Recall, on the other hand, can be determined as seen in Figure 6(Jordan, 2018).

$Precision = TP/(TP + FP);$

$Recall = TP/(TP + FN);$

Figure 8. Formula for Precision and Recall

wherein, TP = True Positives, FP = False Positives, and FN = False Negatives.

Based on the Keypoint Evaluation Metrics used by Common Objects in Context (2021), the loose performance metric used to evaluate object detection and keypoint detection performance are $AP^{IOU=0.50}$ and $AP^{OKS=.50}$ respectively. Since multi-instance keypoint detection performs object detection and keypoint detection simultaneously, it's appropriate that these two metrics are used.

Determining Cobb Angle Measurement Algorithm Performance

Based on the definition by Zaborowska (2022), the accuracy(A) of a measurement can be determined through figure 9.

$A = 100 - P(e);$

$P(e) = [(|X(o) - X(a)|)/X(a)](100);$

Figure 9. Accuracy Formula

Wherein, P(e) is Percent Error, X(o) is Observed Value, and X(a) is Actual Value.

With this in mind, the study makes use of the symmetric mean absolute percentage error (SMAPE) formula as seen in Figure 7. Which summarizes the percent error of all the angles measured on the spine all together.

$$SMAPE = \frac{1}{N}\sum_{N}\frac{SUM[|A - B|]}{SUM[A + B]} \times 100\%$$

Figure 10*. Formula for SMAPE(AASCE, 2019)*

System Usability Evaluation

The quality of the system is evaluated using the ISO 25010 Software Quality Standards. There are eight characteristics that help determine product quality, these are: functional stability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability. Each of these characteristics have their own set of sub-characteristics that further specify the quality of the system.

3.3 Components and Design

3.3.1 Software Architecture

The software architecture in Figure 8 showcases how ScolioVis is made and how its different components interact with one another. To start off, a user inputs a spine image on the front end which is then sent to the backend. Here, the image is preprocessed with OpenCV and transformed into tensors with PyTorch, a readable format for the model. The input tensors are fed into the model to output the bounding boxes and keypoints. The keypoints are then used to measure the Cobb Angle. The final output is then sent back to the frontend as a JSON where the data is drawn and displayed for the user to see.

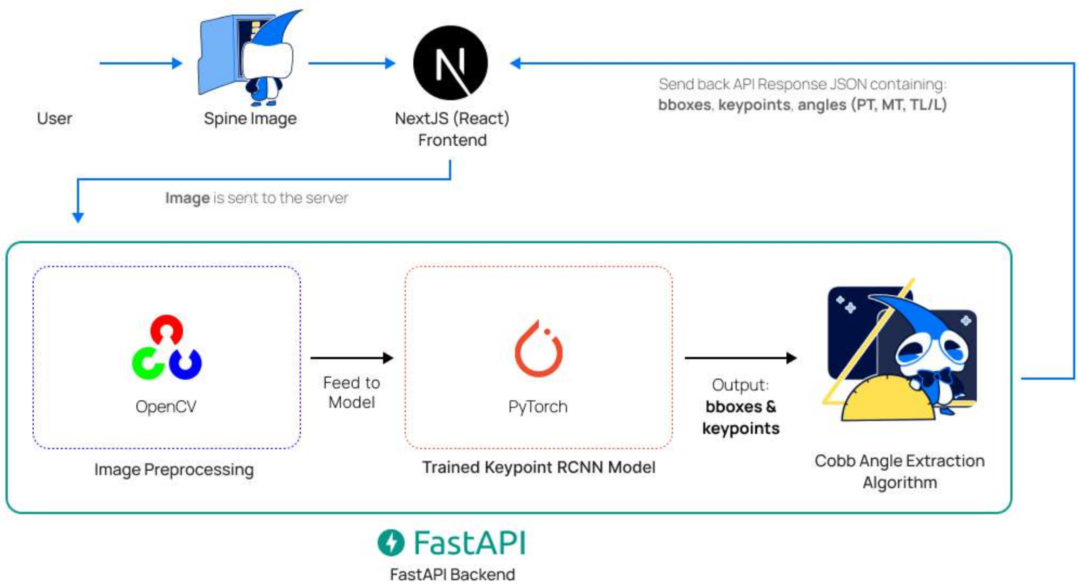

Figure 11. *ScolioVis Software Architecture*

3.3.2 Procedural and Object-Oriented Design

ScolioVis works as seen in Figure 9. The process starts off with the user inputting a spine x-ray image. This image is then sent to the backend for preprocessing.

After preprocessing, it is sent to the model for prediction. If the spine landmark output is not valid, it will display an error, otherwise it will be given to the Cobb angle measurement algorithm for calculations. After measuring the Cobb angle, the output is displayed in the frontend.

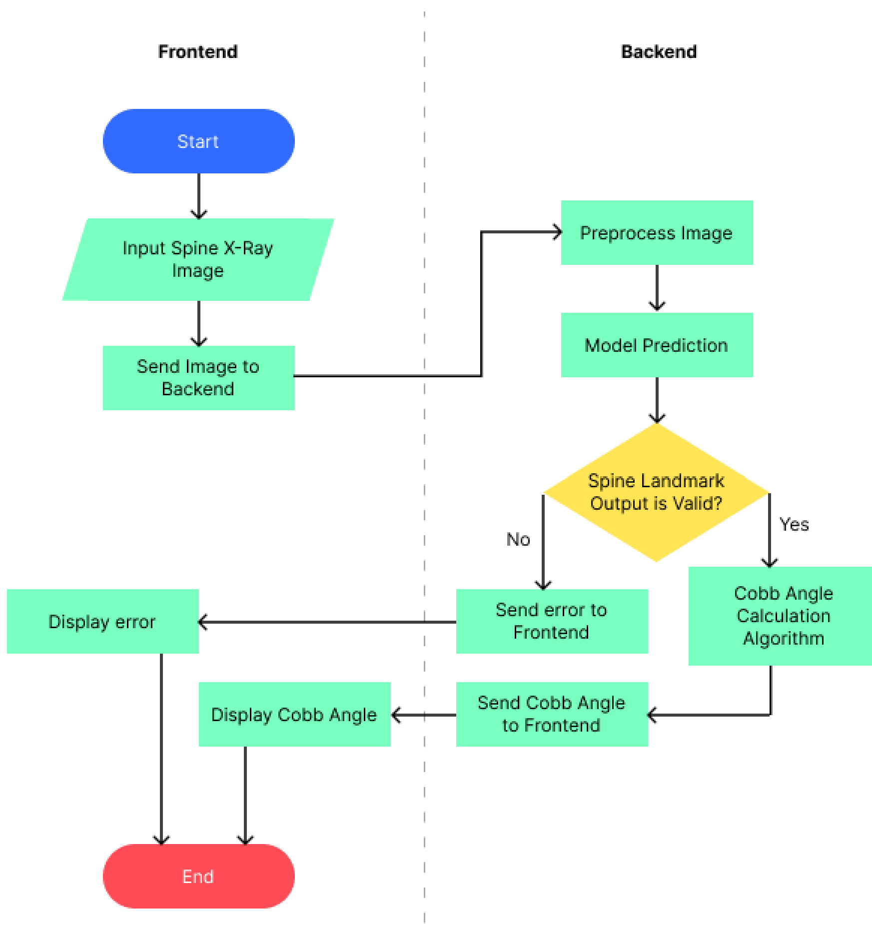

Figure 12. *Procedural Flow Chart of ScolioVis*

3.3.3 Process Design

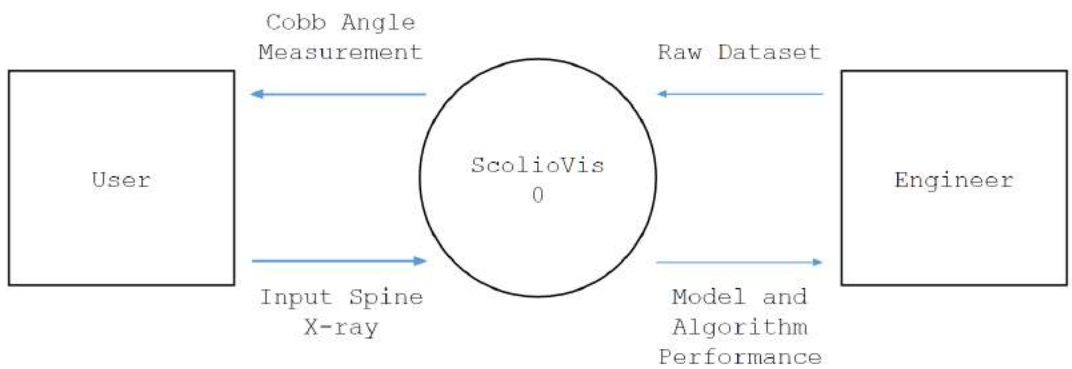

Figure 13. *Level 0 Data Flow Diagram (Context Diagram)*

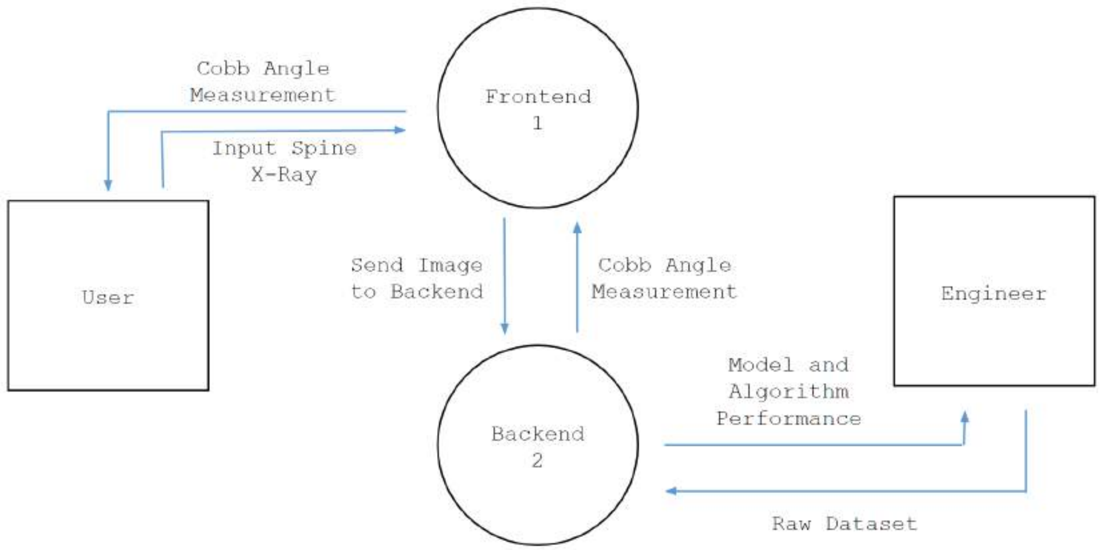

Figure 14. *Level 1 Data Flow Diagram*

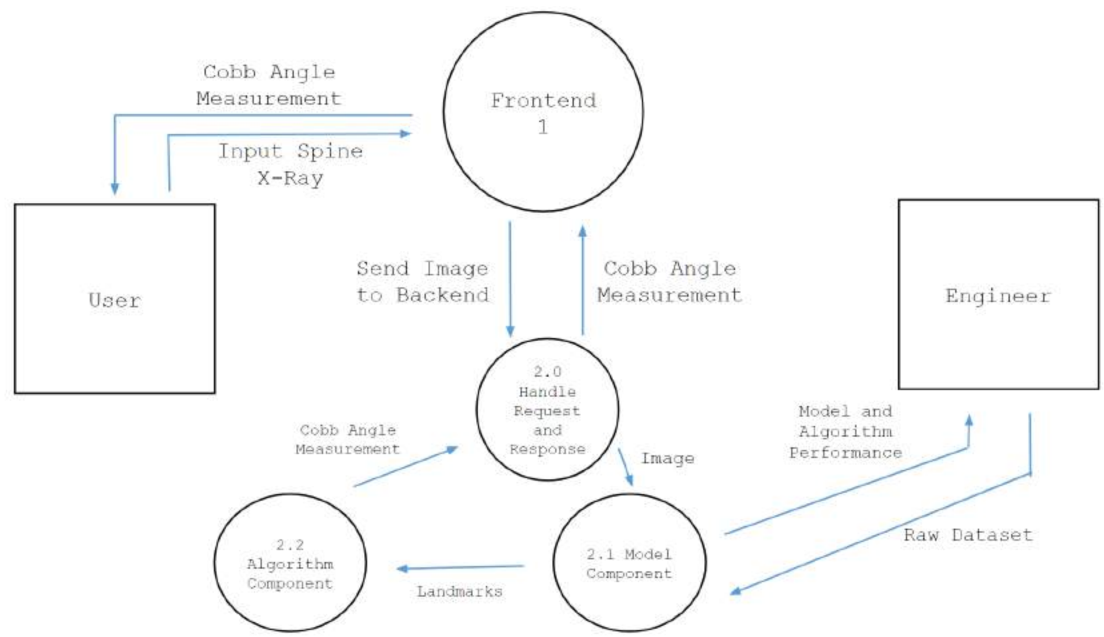

Figure 15. *Level 2 Data Flow Diagram*

As seen in figure 12, ScolioVis is provided with a raw dataset that helps it measure the cobb angle of the Spine X-ray image inputted by the User.

3.3.4 System Development Life Cycle

The study will make use of an Agile Software Development Life Cycle, because of its flexibility and how it allows for rapid prototyping cycles (Singla et al., 2018). Agile practices in software development have become an industry standard as they assist in the collaboration and the efficiency of completing work (Jackson et al., 2019).

Specifically, the Agile SDLC the study will be using is divided into sprints; and each sprint will have 5 phases: Define, Design, Develop, Test, Review, Deploy. In the define phase, the researchers will be defining the current problem that will be the focus for that sprint and design a solution for solving that problem. The design phase will focus on planning out and creating a solution for the problem. The development phase will then focus on implementing the plan to solve the problem. The test phase will determine whether that solution works properly. The review phase will focus on conducting final discussions with the team before proceeding to the last phase, which is the deployment phase. The deploy phase will focus on integrating the current sprint with the main repository which will signal the completion of the sprint.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Implementation

4.1.1 Keypoint Detection Model Training and Testing

Initially, a tensorflow neural network model was developed by the researchers that takes in an input layer size of (256, 128) and performs a multi-output regression task to predict 136 values. Figure 13 shows the initial Keypoint Detection model used by the researchers. Figure 14 shows the model architecture for the initial model. And as seen in Figure 15, the results of the model are extremely inaccurate.

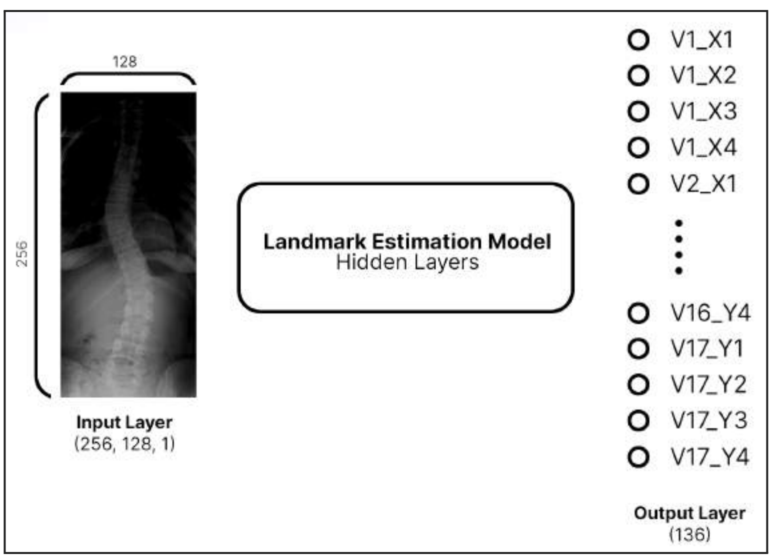

Figure 16. *First Iteration of the Model: The input and output Shapes of the Model*

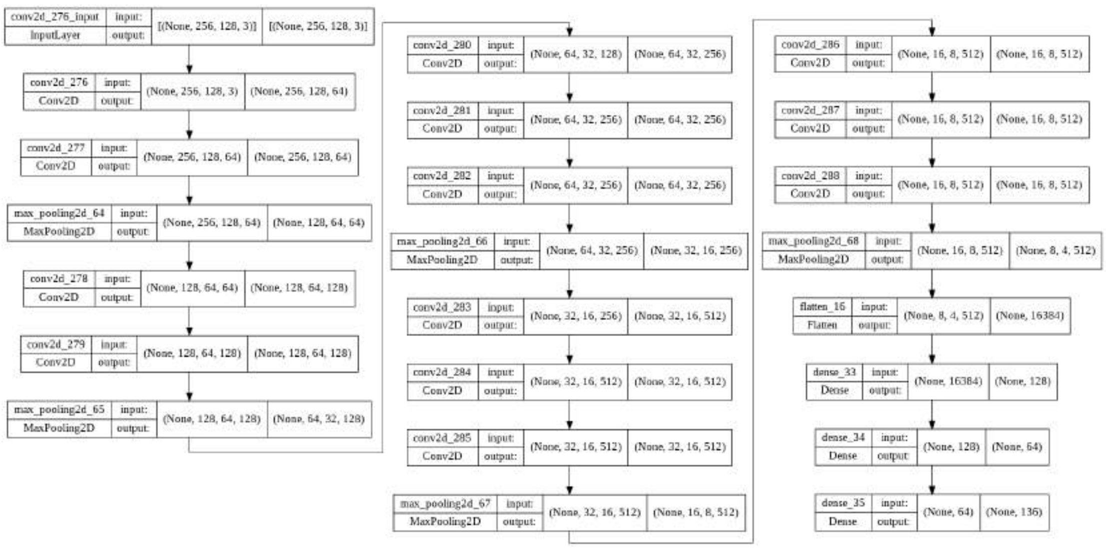

Figure 17. *First iteration of the Model: The Model Architecture*

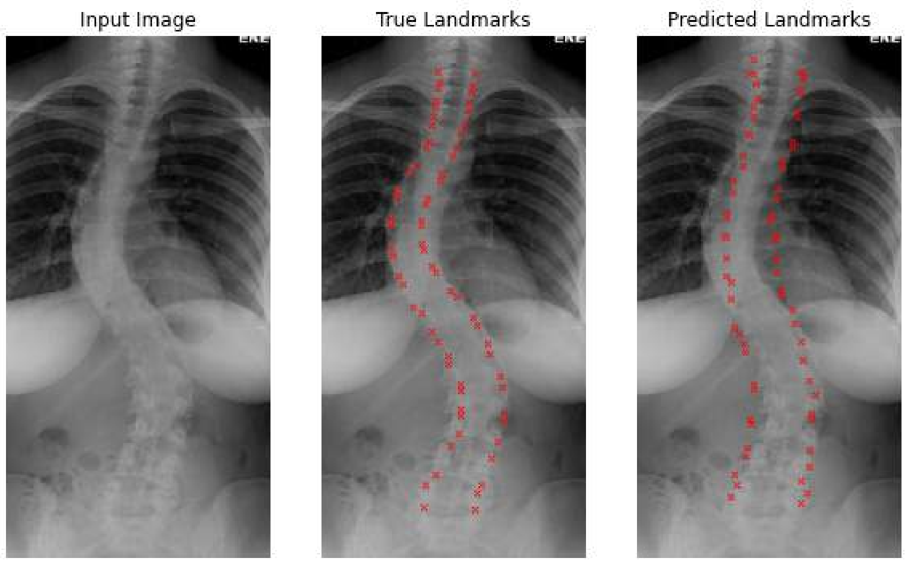

Figure 18. *First Iteration of the Model: Sample Comparison of the Ground-Truth and Predicted Landmarks*

In order to improve the performance, the researchers opted for a Keypoint RCNN to perform multi-instance keypoint detection which simultaneously performs object detection and keypoint detection at the same time. This differs from the initial model as the Keypoint RCNN model is able to take any-sized input tensors and limits the number of keypoints to 4 on each instance, essentially performing localized keypoint detection for every instance found by the object detection step instead of 136 in one operation. The model was developed, trained, and tested using a Google Colab Pro Jupyter Notebook. The specific libraries and packages used were Pytorch, Pandas, Numpy, MatPlotLib, OpenCV, Pycocotools, and Pillow.

Before training, data preprocessing was performed in order for the dataset to be compatible with the chosen Keypoint RCNN model. To be specific, bounding box annotations were not included in the SpineWeb Data 16 so it was calculated by connecting the 4 keypoint corners and extracting the minimum x, minimum y, maximum x, and maximum y from those 4 values, which creates the bounding box data needed for the model. The final preprocessed dataset follows the COCO Keypoint Detection Format (COCO). Figure 16 shows the directory structure of the data after preprocessing.

```
keypointsrcnn_data
├─images
| ├─train
| | ├─img_1.jpg
| | └─(..).jpg
| └─val
|   ├─img.jpg
|   └─(..).jpg
└─labels
| ├─img_1.json
| └─(..).json
└─val
    ├─img.json
    └─(..).json
```

Figure 19. *Final Pre-Processed Data Directory Structure*

As shown in Figure 17, During inference, the model's unfiltered output would have 40 instances, which is a common problem in object detection. This was remedied by applying a threshold of **0.7** on the confidence level to omit the instances that are lower than the threshold. Non-max suppression was also applied on the outputs with an IoU threshold of **0.3** to get rid of the bounding boxes that seem to be predicting the same vertebra. Sometimes the model would detect more than 17 instances, but since the dataset all had exactly 17 vertebrae annotated, the detections were limited to 17 by sorting each detection by confidence and filtering out only the top 17. Lastly, the detections were sorted by their y_min values to create an ordered list of vertebra detections from the top to the bottom of the image.

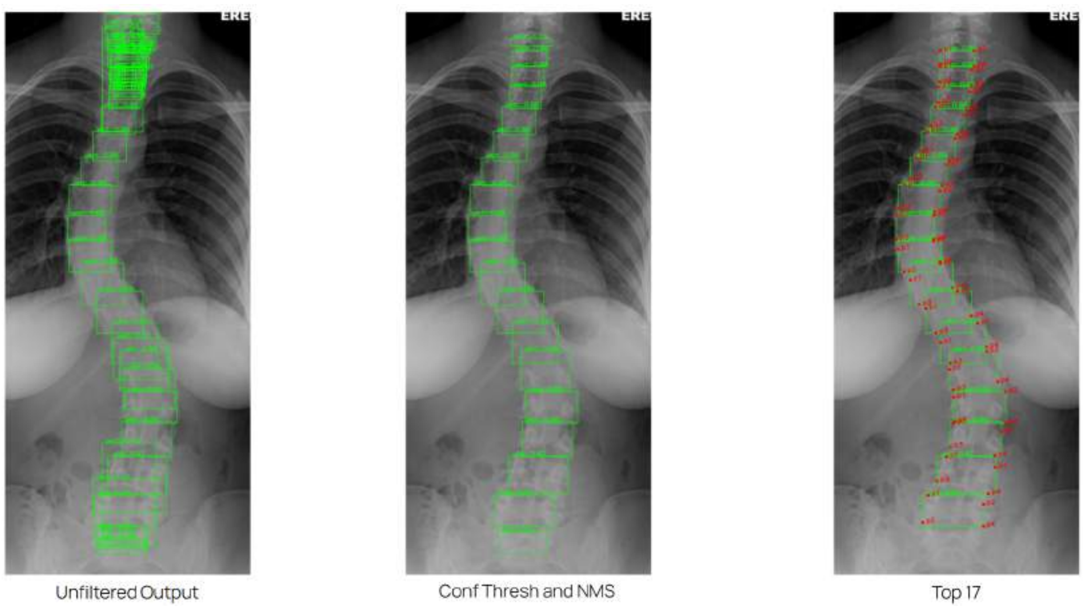

Figure 20. *Model's output (Unfiltered, with Conf Thresh and NMS, and Top 17)*

4.1.2 Designing the Cobb Angle Measurement Algorithm

In figure 18, the ground truth and predicted curve type and angles are shown. The images display the spine x-ray with the green lines representing the vertebrae midlines and the two blue lines representing the upper and lower lines of the largest Cobb Angle. The remaining cyan and magenta lines are used to calculate the remaining curves within the spine.

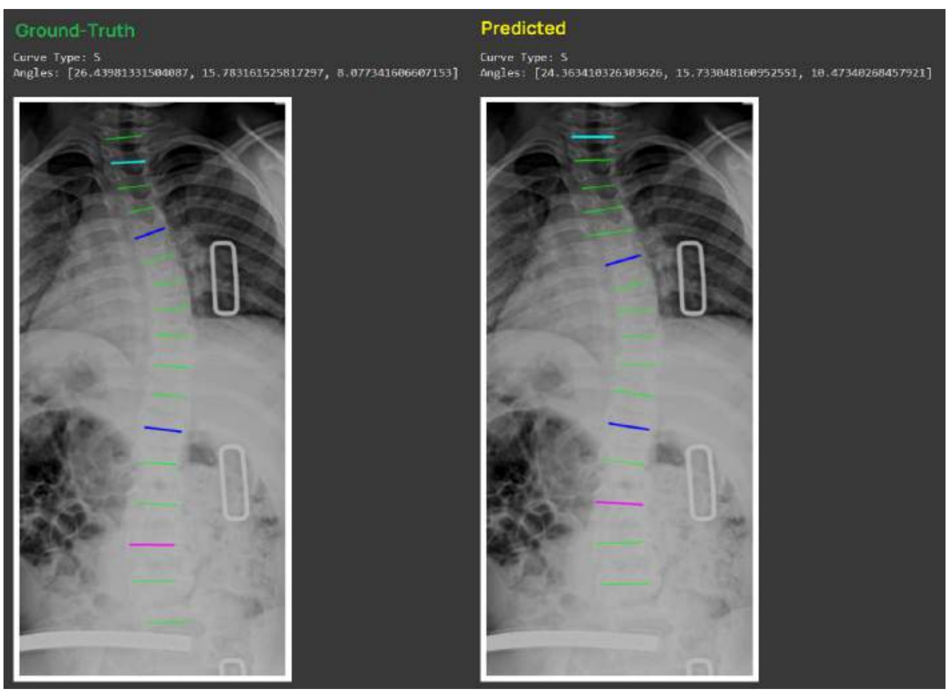

Figure 21. Ground truth vs Predicted

There are minor differences between the ground truth and the predicted midlines and the accuracy of these predictions is quantified in the interpretation and analysis section.

4.1.3 Web Application Development and Model Deployment

As shown in figure 19, the researchers created a simple prototype of the web app during the early stages of the development with only the necessary UI elements to visually show how the input, process, and output flow works for a typical user. The first prototype also gave the researchers ideas on what the final look of the system would look like, without any major design components or actual functionality yet implemented.

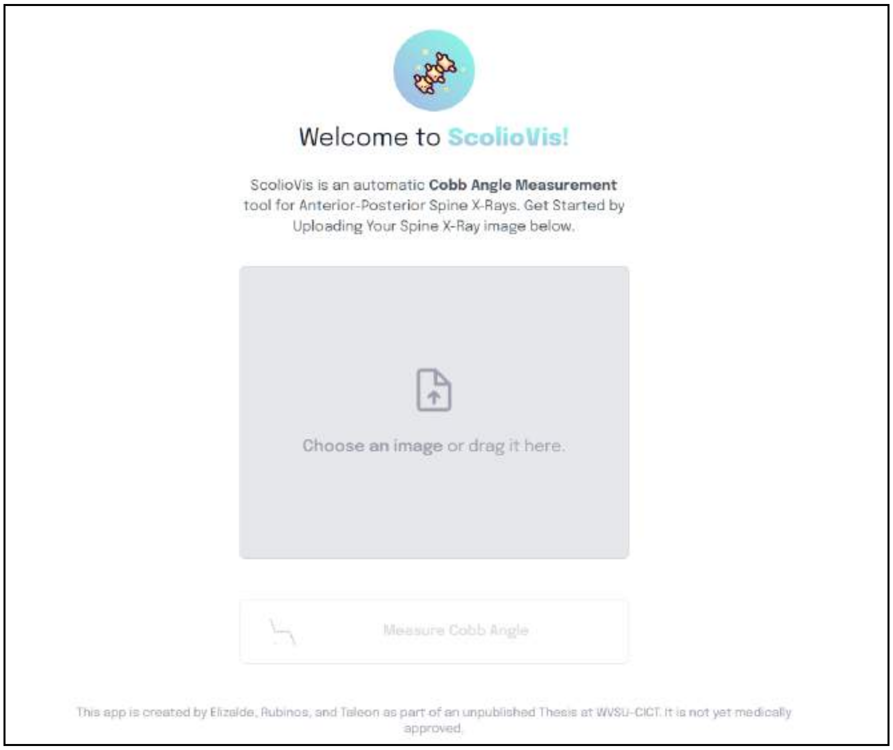

Figure 22. *First Iteration: Web Application Prototype*

Figure 20 shows the sample screenshots of the second iteration of the web app which contains the Home Page, and Main App Window State Changes. The Home Page UI which serves as an entry point to the main application. After selecting an image, the system sends the image to the FastAPI backend for the landmark estimation model to begin processing. The API then returns an output of the same spine image with the estimated landmarks on the second column as shown in figure 20.

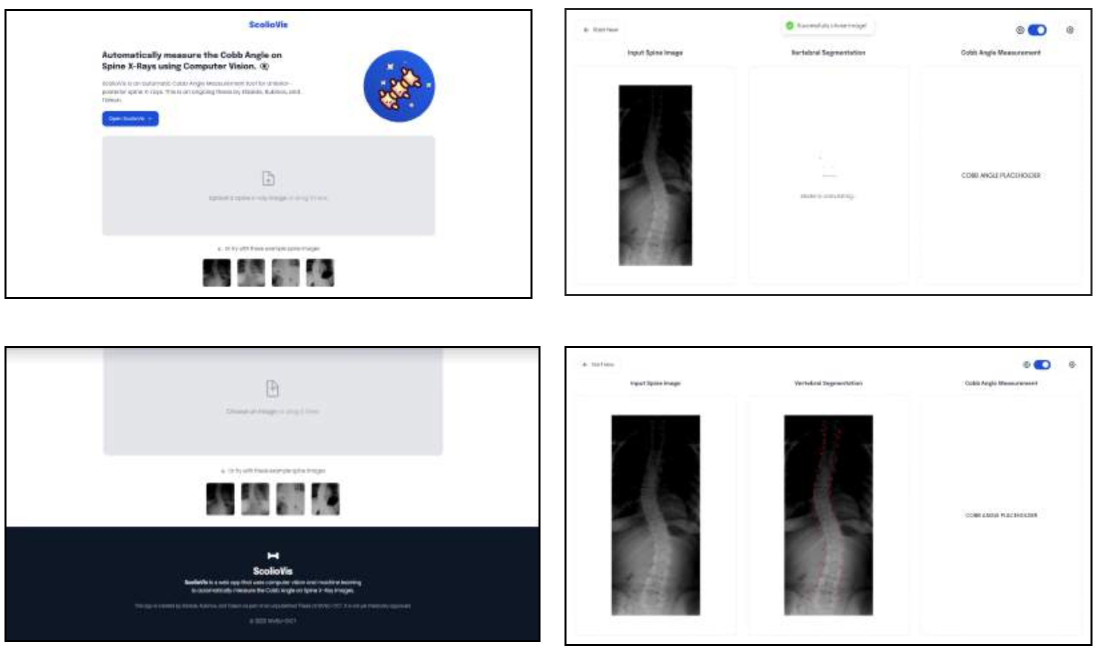

Figure 23. *Second Iteration of the Web App*

The final iteration of the application is shown on Figure 21-22 which features a highly polished frontend and a high-fidelity design implemented as well as other pages to help educate first-time users on what the application is all about and how it works. There are also several custom illustrations of the ScolioVis mascot, “Apex”. Figure 22 shows the main application page which features a powerful visualization tool so that users view the model predictions and cobb angle results however they want. The final iteration of web app is available at https://scoliovis.vercel.app/

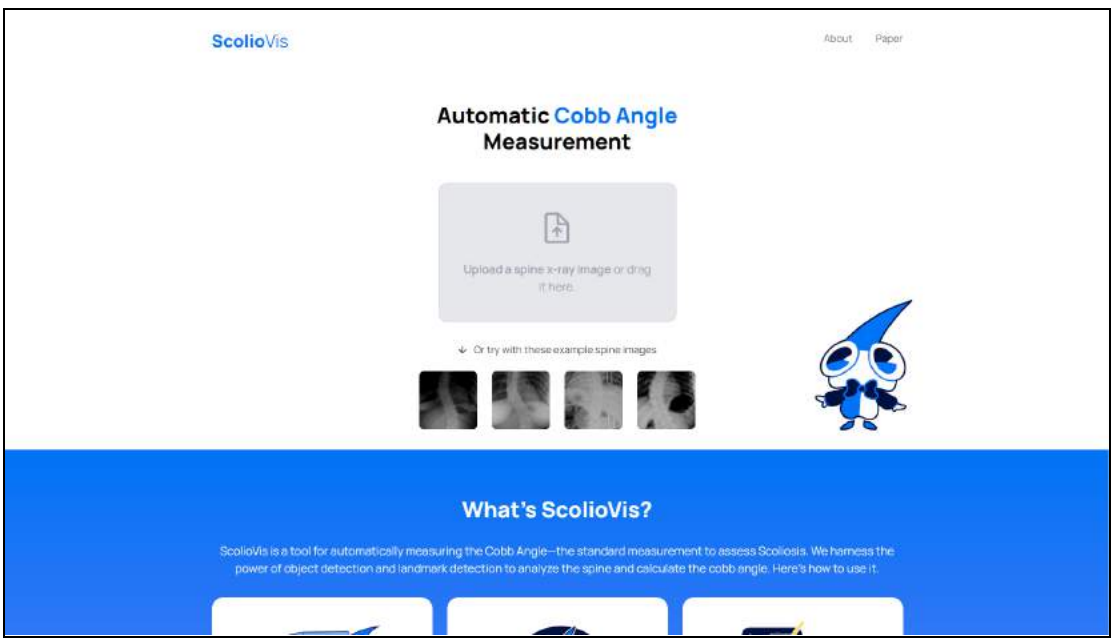

Figure 23.a *Final Iteration: Home Page 1*

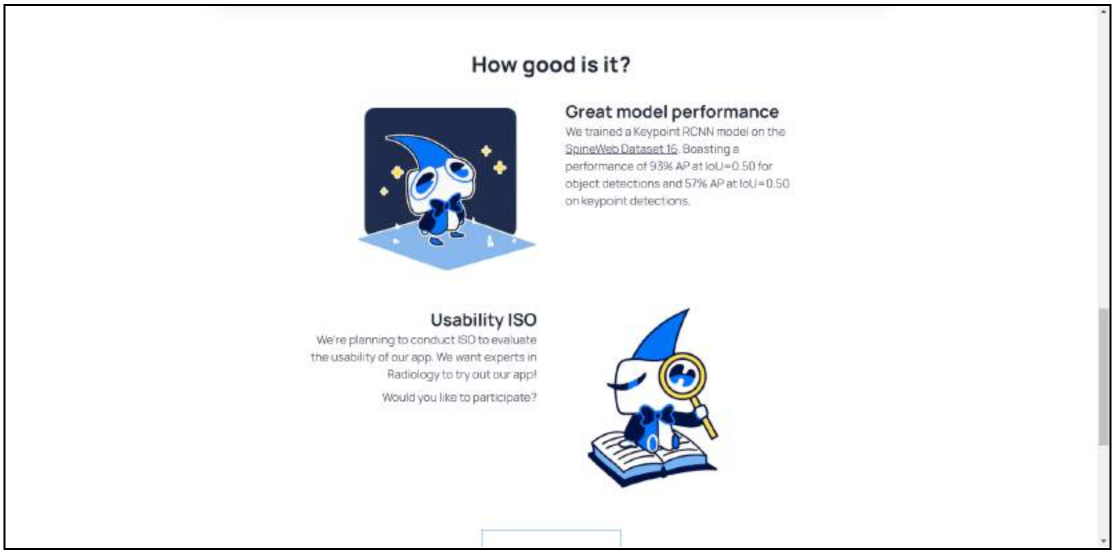

Figure 23.b. *Final Iteration: Home Page 2*

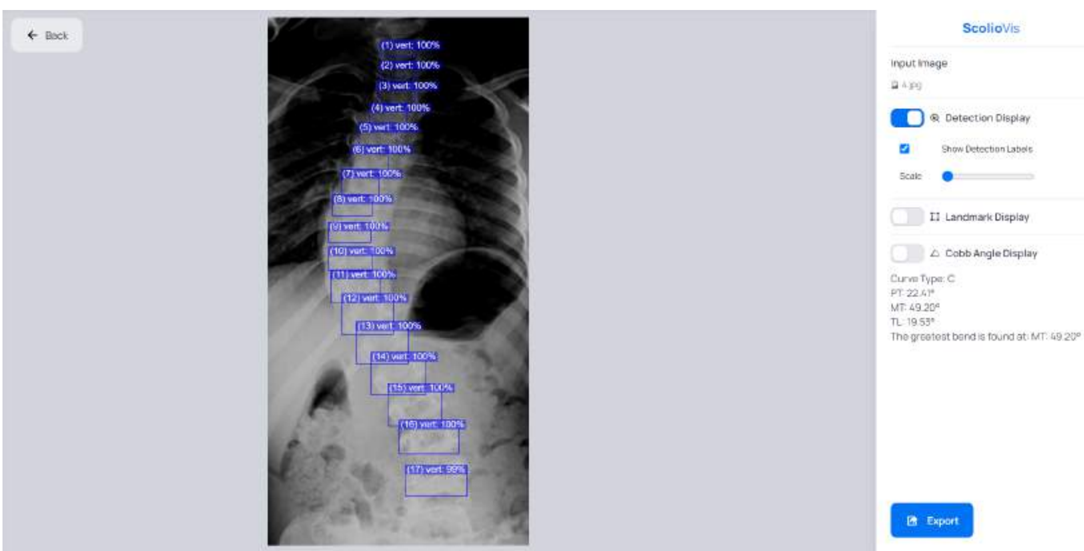

Figure 24. *Final Iteration: App Page*

The researchers chose to develop the system with a development stack as shown in Figure 23. The frontend uses Typescript as the main programming language, NextJS and React, TailwindCSS for styling, and finally deployed on the Vercel Platform. The backend is developed using Python as the main programming language, PyTorch for loading the Keypoint RCNN model, OpenCV for preprocessing images, FastAPI for handling routes and running the backend service, and finally deployed on the Heroku Platform.

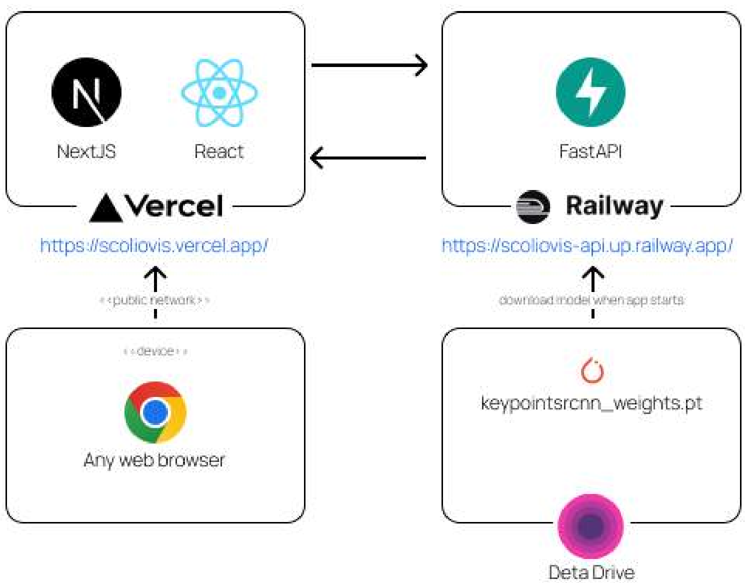

Figure 25. *Technology Stack and Deployment Diagram of the Web App*

4.2 Results Interpretation and Analysis

4.2.1 Keypoint Detection Model Performance

The model was trained over 70 epochs. Figure 24-25 provide a visual representation of the model's metrics over every epoch of training. Figure 24 specifically highlights the performance of the Keypoint RCNN model on previously unseen data. The final model performance achieved is **$AP^{IOU=0.50}$ 0.933** for object detection (boxes) and **$AP^{OKS=.50}$ of 0.566** for keypoint detection. The results demonstrate the learning efficacy of the model as the metrics change overtime.

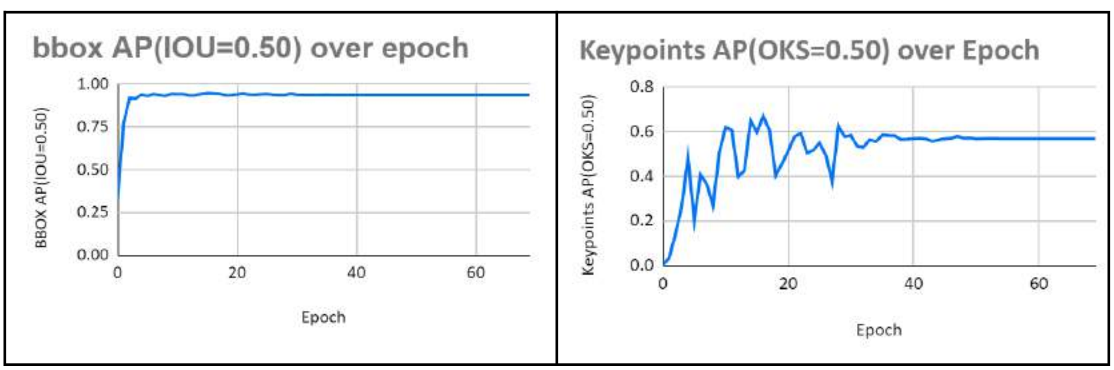

Figure 26. *Keypoint RCNN performance evaluation metrics on validation set*

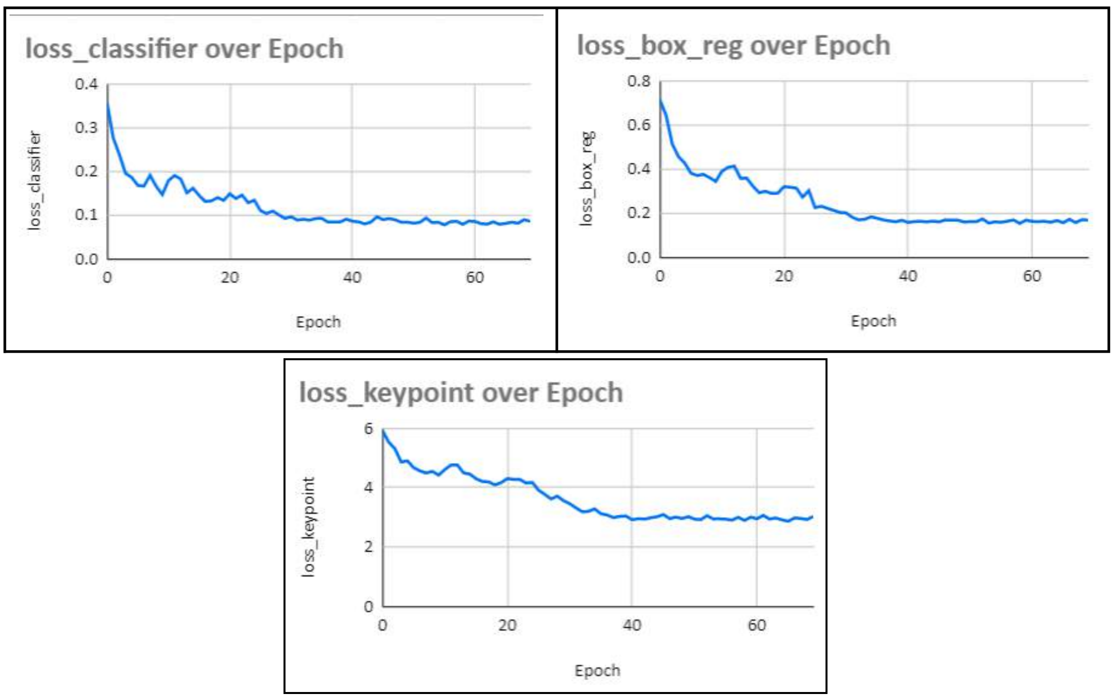

Figure 27. *Loss over epoch of classifier, box_reg, and keypoint during Training*

4.2.2 Cobb Angle Measurement Performance

The evaluation of the Cobb Angle Measurement revealed promising results, as demonstrated in Table 1. The cobb angle measurement algorithm achieved an SMAPE of 8.966294821 with an accuracy of 91.03370518%. However, it is worth noting that it failed to calculate the cobb angles of 6 x-rays out of a dataset of 128. The accuracy rate of 91.033070518% achieved by ScolioVis surpasses the accuracy of the first prize winner in the Accurate Automated Spinal Curvature Estimation (AASCE) 2019 Grand Challenge, which had an SMAPE of 21.7135, or 78.2865% accurate (AASCE, 2019). These results demonstrate the potential for ScolioVis to contribute positively to the field of spinal curvature measurement. See Appendix O for more detailed information on the SMAPE calculation.

Table 1. Cobb Angle Measurement Accuracy

N =	122
SMAPE =	8.966294821
Accuracy =	91.03370518

4.3 System Evaluation Results

Table 2. Summary of ISO/IEC 25010 Software Quality Standards Evaluation Results

Characteristics	Mean	Description
Functional Stability	4.380952381	Very Good
Performance Efficiency	4.380952381	Very Good
Compatibility	4.285714286	Very Good
Usability	4.261904762	Very Good
Security	4.464285714	Very Good
Reliability	4.25	Very Good
Maintainability	4.542857143	Very Good
Portability	4.523809524	Very Good
OVERALL	**4.386309524**	**Very Good**

Table 3. ISO/IEC 25010 Software Quality Standards Evaluation Legend

Scales of Mean	Description
5 - 4.1	Very Good
4 - 3.1	Good
3 - 2.1	Far

2 - 1.1	Poor
1	Very Poor

The system was evaluated using the ISO/IEC 25010 as the standard evaluation framework. A total of 7 respondents composed of Radiology Residents, Consultant Radiologists, and Physicians were chosen to participate in the data gathering. The results of the evaluation, as presented in Table 2, indicate that all eight characteristics assessed by the instrument, namely Functional Stability, Performance Efficiency, Compatibility, Usability, Security, Reliability, Maintainability, and Portability are all "Very Good", with an overall mean of 4.39. This demonstrates the system's overall high level of quality and effectiveness in meeting the needs of users. See Appendix Q for more detailed information on the ISO/IEC 25010 results.

CHAPTER 5 SUMMARY, CONCLUSIONS, RECOMMENDATIONS

5.1 Summary of the Proposed Study Design and Implementation

The final model and cobb angle measurement algorithm were both implemented into the web application. The final design takes in x-ray images and locates the vertebrae and then uses it to determine the four key points of each individual vertebra. The app then uses the key points to return the measurements and appropriately labels them PT, MT, and TL/L.

5.2 Summary of Findings and Conclusions

ScolioVis boasts a performance of **93% $AP^{IoU=0.50}$** for object detections and **57% $AP^{OKS=0.50}$** on keypoint detections. For cobb angle measurement, the system achieved an **SMAPE of 8.97** which means ScolioVis is able to predict cobb angles at **91.03% accuracy.** Additionally, the system was evaluated using the ISO/IEC 25010 standard evaluation framework, and demonstrated a high level of quality and effectiveness in meeting the needs of users, with all eight characteristics assessed being rated as **"Very Good".**

5.3 Recommendations

In terms of improving the results for future related studies, it’s recommended that data augmentation is applied as an additional step before training. Due to the lack of time and computing resources, the researchers were not able to apply this as this would have doubled the training time.

Another approach that the researchers wished to try was to make use of a separate model for object detection like YoloV5 and another separate model for localized keypoint detection model of 4 keypoints. The researchers were able to train a YoloV5 model with 96% mean average precision (mAP) which has a very promising potential if paired with another model. For that model, the researchers suggest creating a custom keypoint detection model that essentially performs a multi-output regression of 8 values (4 keypoints) using a ResNet50 as a backbone for feature extraction. Furthermore, data augmentation may also be applied to improve accuracy.

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APPENDICES

Appendix A - Letter to the Adviser

Dr. Frank Elijorde

Attachment 3

	INVITATION LETTER FOR ADVISER	Document No.	WVSU-ICT-SOI-03-F03
		Issue No.	1
		Revision No.	0
	WEST VISAYAS STATE UNIVERSITY	Date of Effectivity:	April 27, 2018
		Issued by:	CICT
		Page No.	Page 1 of 1

January 21, 2022

DR. FRANK I. ELIJORDE
Associate Dean, Associate Professor IV
CICT - WVSU
Luna St, La Paz, Iloilo City

Dear Dr. Elijorde,

The undersigned are BS in Computer Science Research 1/Thesis 1 students of CICT, this university. Our thesis/capstone project title is *"SCOLIOVIS: COMPUTER VISION ALGORITHM FOR AUTOMATED COBB'S ANGLE MEASUREMENT ON FRONTAL SPINE X-RAYS FOR SCOLIOSIS"*.

Knowing of your expertise in research and on the subject matter, we would like to request you to be our **ADVISER**.

We are positively hoping for your acceptance. Kindly check the corresponding box and affix your signature in the space provided. Thank you very much.

Respectfully yours,

1. Carlo Antonio Taleon
2. Glecy Elizalde
3. Christopher Joseph Rubinos

PS:

Advisers, are task to work with the students in providing direction and assistance as needed in their thesis/capstone project. They shall meet with the students weekly or as needed to provide direction, check on progress and assist in resolving problems until such a time that the students passed their defenses and submit their final requirements, as well as, preparing their evaluations and grades.

Action Taken:
- ❍ I Accept.
- ❍ Sorry. I don't accept.

Signature over printed name of the Adviser

CC:

CICT Dean
Research Coordinator
Group
**To be accomplished in 4 copies*

Dr. Bobby Gerardo

Attachment 3

	INVITATION LETTER FOR ADVISER	Document No.	WVSU-ICT-SOI-03-F03
		Issue No.	1
		Revision No.	0
	WEST VISAYAS STATE UNIVERSITY	Date of Effectivity:	April 27, 2018
		Issued by:	CICT
		Page No.	Page 1 of 1

January 21, 2022

DR. BOBBY D. GERARDO
Graduate Studies Coordinator, Professor VI
CICT - WVSU
Luna St, La Paz, Iloilo City

Dear Dr. Gerardo,

The undersigned are BS in Computer Science Research 1/Thesis 1 students of CICT, this university. Our thesis/capstone project title is *"SCOLIOVIS: COMPUTER VISION ALGORITHM FOR AUTOMATED COBB'S ANGLE MEASUREMENT ON FRONTAL SPINE X-RAYS FOR SCOLIOSIS"*.

Knowing of your expertise in research and on the subject matter, we would like to request you to be our **ADVISER**.

We are positively hoping for your acceptance. Kindly check the corresponding box and affix your signature in the space provided. Thank you very much.

Respectfully yours,

1. Carlo Antonio Taleon
2. Glecy Elizalde
3. Christopher Joseph Rubinos

PS:

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Action Taken:	
❍ I Accept.	
❍ Sorry. I don't accept.	Signature over printed name of the Adviser

CC:

CICT Dean
Research Coordinator
Group
To be accomplished in 4 copies

Appendix B - Consultation Letter to Radiologist

West Visayas State University
COLLEGE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY
Luna St., La Paz, Iloilo City 5000
Iloilo, Philippines
* Trunkline: (083) (033) 320-0870 loc 1403 * Telefax No.: (033) 320-0879
* Website: www.wvsu.edu.ph * Email Address: cict@wvsu.edu.ph

SOCOTEC ISO 9001
JAS-ANZ
PHI-18026-2-QM

June 1, 2022

Dr. JOCELYN F. VILLANUEVA
Radiologist
Medicus Medical Center
Dra. Rizalina V Bernardo Avenue
Brgy. San Rafael, Mandurriao, Iloilo City

Dear Dr. Villanueva,

Greetings!

I am a 3rd Year BS Computer Science Students of West Visayas State University from the College of Information and Communication Technology and my Team are currently working on the study entitled **"ScolioVis: Computer Vision Algorithm For Automated Cobb Angle Measurement On Anterior-Posterior Spine X-Ray Images For Scoliosis"** as a requirement for "CCS 232: Thesis Writing for CS 1".

Our research is about the use of artificial intelligence to automatically measure the Cobb Angle from a spinal x-ray image.

With this in mind, my Team and I would like to ask for your assistance and consult with you about the topics related to our study as follows:

1. Brief Summary of Our Study
2. Cobb Angle Measurement
3. Different types of Scoliosis and how the are measured
4. Sources of Local Spine X-Rays

Hoping for your accommodation.

Respectfully yours,

GLECY S. ELIZALDE
Researcher

Co-Researchers:
CARLO ANTONIO TALEON
CHRISTOPHER JOSEPH RUBINOS

cc: Dr. REGIN CABACAS - WVSU CCS 232 Instructor
Thesis Advisers:
Dr. FRANK ELIJORDE
Dr. BOBBY GERARDO

Glecy S. Elizalde / Contact No. Smart Cel. No. 09422451590

Appendix C - Consultation Letter to Statistician

West Visayas State University
COLLEGE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY
Luna St., La Paz, Iloilo City 5000
Iloilo, Philippines
* Trunkline: (063) (033) 320-0870 loc 1403 * Telefax No.: (033) 320-0879
* Website: www.wvsu.edu.ph * Email Address: cict@wvsu.edu.ph

PHI-18939-2-QM

June 14, 2022

Paolo G. Hilado, MN, DRDM
Director, Research and Planning Office
Colegio San Agustin
Bacolod

Dear Sir Hilado,

Greetings!

We are 3rd Year BS Computer Science Students of the College of Information and Communications Technology - West Visayas State University (WVSU). We're currently working on our research study entitled **"ScolioVis: Computer Vision Algorithm For Automated Cobb Angle Measurement On Anterior-Posterior Spine X-Ray Images For Scoliosis"** as a requirement for "CCS 232: Thesis Writing for CS 1". Our research is about the use of artificial intelligence to automatically measure the Cobb Angle from a spinal x-ray image.

Knowing fully well your expertise in Research and Data Science, We would like to ask for your assistance and consult with you about the appropriate statistical analysis methods and tools associated with the type of data we are about to collect in our study.

If you are interested, we hope to be able to agree on a time and means of consultation convenient to you.

Your favorable response to this request will be highly appreciated. Thank you and God bless.

Respectfully yours,

(Sgd.) CARLO ANTONIO T. TALEON
(Sgd.) GLECY S. ELIZALDE
(Sgd.) CHRISTOPHER JOSEPH T. RUBINOS
Student Researchers

Concurred with:
(Sgd.) DR. FRANK ELIJORDE
Research Adviser

Appendix D - Consultation Log

Attachment 4

	THESIS/CAPSTONE PROJECT CONSULTATION LOG FORM	Document No.	WVSU-ICT-SOI-03-F04
		Issue No.	1
		Revision No.	0
	WEST VISAYAS STATE UNIVERSITY	Date of Effectivity:	**April 27, 2018**
		Issued by:	**ICT OFFICE**
		Page No.	**Page 1 of 3**

Academic Year 2021-2022

Group Members:	
1. ELIZALDE, GLECY	4.
2. RUBINOS, CHRISTOPHER JOSEPH	5.
3. TALEON, CARLO ANTONIO	6.

Date	Attendance	Comments/Suggestions/Instructions	Signature
3/23/2022	Consultant: • Dr. Frank I. Elijorde Consultees: • Elizalde • Rubinos • Taleon	• Provided recommendations and improvements on First Draft's chapter 1 to 3 • Appropriate Format of theoretical framework and significance of the study • Breakdown the Review of Related lit. to Subsections • Consult Experts regarding the methodology • etc.	
3/26/2022	Consultant: • Dr. Bobby D. Gerardo Consultees: • Elizalde • Rubinos • Taleon	• Be more specific in objectives • Perform validation • validate with experts output (their manual calculation) their impression on the picture/graphic • develop steps of algorithm • later on for validation can make use of actual local datasets • enhancement on the algorithm (steps that we will translate to computations), target should be to increase accuracy, image optimization	
5/30/2022	Consultant: • Dr. Frank I. Elijorde Consultees: • Elizalde • Rubinos • Taleon	Discussed recommendations from 20% thesis presentation • Clarified how interactions with experts should be handled and applied to the thesis • Implement "ensemble algorithm" into the thesis title and elaborate within the paper • On usability testing, use ISO 205010 to determine software quality • Suggested changes to the objectives, add "ensemble algorithms" and usability testing • Discussed what needs to be done for the 50% presentation, and comply towards completing objectives.	

Attachment 4

	THESIS/CAPSTONE PROJECT CONSULTATION LOG FORM	Document No.	**WVSU-ICT-SOI-03-F04**
		Issue No.	**1**
		Revision No.	**0**
	WEST VISAYAS STATE UNIVERSITY	Date of Effectivity:	**April 27, 2018**
		Issued by:	**ICT OFFICE**
		Page No.	**Page 2 of 3**

6/17/2022	Consultant: Mr. Paolo G. Hilado Consultees: • Elizalde • Rubinos • Taleon	• Clarified objectives that involve statistical hypothesis testing (significant difference). • Hypothesis testing is easier said than done. It needs two prerequisites to be technically sound: a computed sample size and randomization. • If we were to perform inferential analysis, just make sure we have the right resources like time and a large enough sample size to satisfy the computed sample size from power and mean. • Suggested an alternative: Is inferential analysis really required for your study? Because in studies powered by machine learning, there are already certain measures for error that can also be used for accuracy. • In the industry, when we come up with machine learning models/applications, there's no need to perform statistical hypothesis testing like the significant difference. What's important is presenting the accuracy and the error, only showing the algorithmic perspective. • In data science we use accuracy. Significant difference belongs to statistics.	
6/23/2022	Consultant: Dr. Jocelyn F. Villanueva Consultees: • Elizalde • Taleon	• Minimum of 10 degrees to count as scoliosis • Two types of scoliosis based on direction: Levoscoliosis(left), and Dextroscoliosis(right). • Patients should be properly positioned in the X-ray to get a proper reading. • No difference in method of Cobb Angle Measurement based on age. • Current method in measurement is semi-automatic. • The study would be beneficial to orthopedists. • Types of scoliosis based on location: T dex/L, L dex/L, TL dex/L.	
8/2/2022	Consultant: Dr. Bobby G. Gerardo Consultees: Elizalde Taleon	Notes: - 50% progress report - recommendation of a computer vision specialists	
8/8/2022	Consultant: Dr. Frank Elijorde Consultees: Elizalde Taleon Rubinos	Notes: -50% progress report - When consulting people outside the college, the standard practice is to have proper documentation that can be put in appendices. - There is enough displayed for performance, but the model should be further optimized. - Discussed ISO 25010 and how the system gets evaluated at a user level. -Referred Dr. SALIDO As a consultant	

Attachment 4

	THESIS/CAPSTONE PROJECT CONSULTATION LOG FORM	Document No.	**WVSU-ICT-SOI-03-F04**
		Issue No.	**1**
		Revision No.	**0**
	WEST VISAYAS STATE UNIVERSITY	Date of Effectivity:	**April 27, 2018**
		Issued by:	**ICT OFFICE**
		Page No.	**Page 3 of 3**

8/8/2022	Consultant: Dr. Julie Ann Salido Consultees: Elizalde Taleon Rubinos	Notes: - Try segmentation with image processing first before inputting to the model and if it improves performance. - Or do object detection first before landmark estimation/keypoint detection. - Show that there is a need for this system, how many experts there are in PH, Iloilo - Emphasize on quantitative metrics.	**Noted**
11/17/2022	Consultant: Dr. Frank Elijorde Consultees: Elizalde Taleon	Notes: - Inform panelist regarding the inclusion of ISO evaluation on the manuscript - Copy of ISO was provided - Prepare advisor's recommendation sheet - Majority of the study is ready and there no further concerns	
11/17/2022	Consultant: Dr. Christopher Barrera Consultees: Elizalde Taleon Rubinos	Notes: - Usual Results: There is rightward lateral curvature of the thoracolumbar spine with cobb's angle of __deg taken from the superior endplate of T3 and inferior endplate of L4. - Dextroscoliosis (right side curve) - Levoscoliosis (left side curve) - More than 10 deg is usually diagnosed as scoliosis - Usual number of angles found for "C" curves=1. For "S" curves=2. The biggest angle is the most important.	

Adviser:

DR. FRANK I. ELIJORDE

Consultation Schedule: ______________________________

Appendix E - Final Defense Adviser's Recommendation Letter

Attachment 7

	ADVISER'S RECOMMENDATIONS	Document No.	WVSU-ICT-SOI-03-F07
		Issue No.	1
		Revision No.	0
	WEST VISAYAS STATE UNIVERSITY	Date of Effectivity:	**April 27, 2018**
		Issued by:	**CICT**
		Page No.	**Page 1 of 1**

(For Thesis Defense)

☐ 20% ☐ 50% ☑ Final Defense

This is to certify that the thesis entitled:

SCOLIOVIS: AUTOMATED COBB ANGLE MEASUREMENT ON ANTERIOR-POSTERIOR SPINE X-RAYS USING MULTI-INSTANCE KEYPOINT DETECTION WITH KEYPOINT RCNN

has been presented to me by the proponents whose names indicated below, and has been preliminarily evaluated and is ready for the Defense Evaluation.

Now therefore, I hereby **RECOMMEND/ENDORSE** the said thesis group (with their thesis document and system) for evaluation by the panel of Jurors for THESIS DEFENSE as scheduled.

DR. FRANK I. ELIJORDE
Adviser's Name & Signature

DR. BOBBY D. GERARDO
Name of Co-Adviser (if there is any)

Date: 11/18/2022

Group Members:

1. ELIZALDE, GLECY
2. RUBINOS, CHRISTOPHER JOSEPH
3. TALEON, CARLO ANTONIO

Note: *This form should be placed on top of the thesis document that will be submitted for the defense. No group will be entertained in the defense without this document.*

Appendix F - Letter of Request to the Adviser for Endorsement

<To add>

Appendix G - Letter of Request to the Technical Editor

<To add>

Appendix H - Letter of Request to the English Editor

<To add>

Appendix I - Letter of Request to the Thesis Format Editor

<To add>

Appendix J - Letter of Request to the Thesis Coordinator/Certification for Bookbinding

<To add>

Appendix K - Signed Letter for Output and Final Build Evaluation

<To add>

Appendix L - Gantt Chart

<To add>

Appendix M - Dataset Screenshots

Training Images (481 Anterior-Posterior X-ray Images)

Testing Images (128 Anterior-Posterior X-ray Images)

Appendix N - ISO/IEC 25010 Evaluation Questionnaire

ScolioVis ISO/IEC 25010 EVALUATION QUESTIONNAIRE

Good Day! We, students from West Visayas State University - College of Information and Communications Technology ask for your participation in our research entitled: *"Scoliovis: Automated Cobb Angle Measurement on Anterior-Posterior Spine X-Rays using Multi-Instance Keypoint Detection with Keypoint RCNN"*.

We created an app that can automatically measure the **Cobb Angle**, the standard measure for the severity of scoliosis, by utilizing machine learning and computer vision. All you have to do is upload an image of a spine x-ray in our app and it will report the angles for you!

This questionnaire will take only 5-10 minutes and all responses will remain strictly confidential.

Instructions:
1. Try the app: https://scoliovis.app/

2. After accessing and running the system/software from the web address provided, kindly evaluate the degree of compliance of the system/software to the ISO/IEC 25010:2011 System and Software Quality Requirements and Evaluation criteria by checking the column corresponding the degree to which you deemed the system/software being evaluated complied or achieved using the scale below.

Thank you for your time!

Email *

Your email

Name (Optional)

Your answer

Position *

Your answer

Email Address (Optional)

Your answer

Functional Stability

Degree to which a product or system provides function as that meet stated and implied needs when used under specified condition

1. Functional Completeness. Degree to which a set of functions covers all the specified task and user objectives. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

2. Functional Correctness. Degree to which a product or system provides the correct results with the needed degree of precision. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

3. Functional Appropriateness. Degree to which the function facilitate the accomplishment of specified task and objectives *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

Performance Efficiency

Performance relative to the amount of resources used under stated condition.

1. Time Behavior. Degree to which the response and processing times and throughput rates of a product or system, when performing its function, meet requirements. *

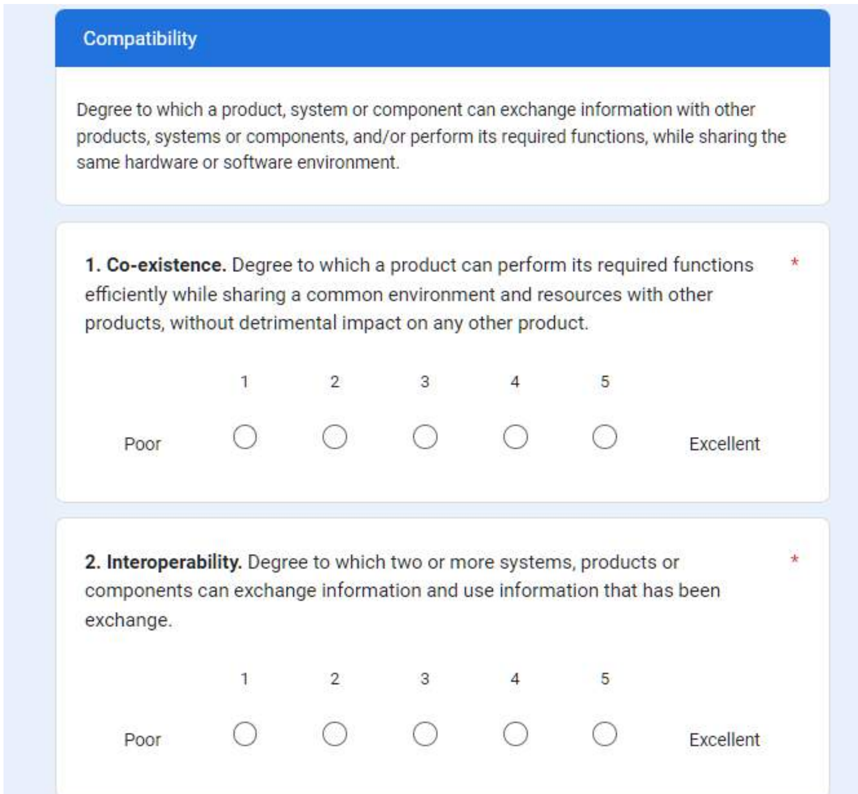
	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

2. Resource Utilization. Degree to which the amounts and types of resources used by a product or system, when performing its function, meet requirements. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

3. Capacity. Degree to which the maximum limits of a product or system parameter meet requirements. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent



Compatibility

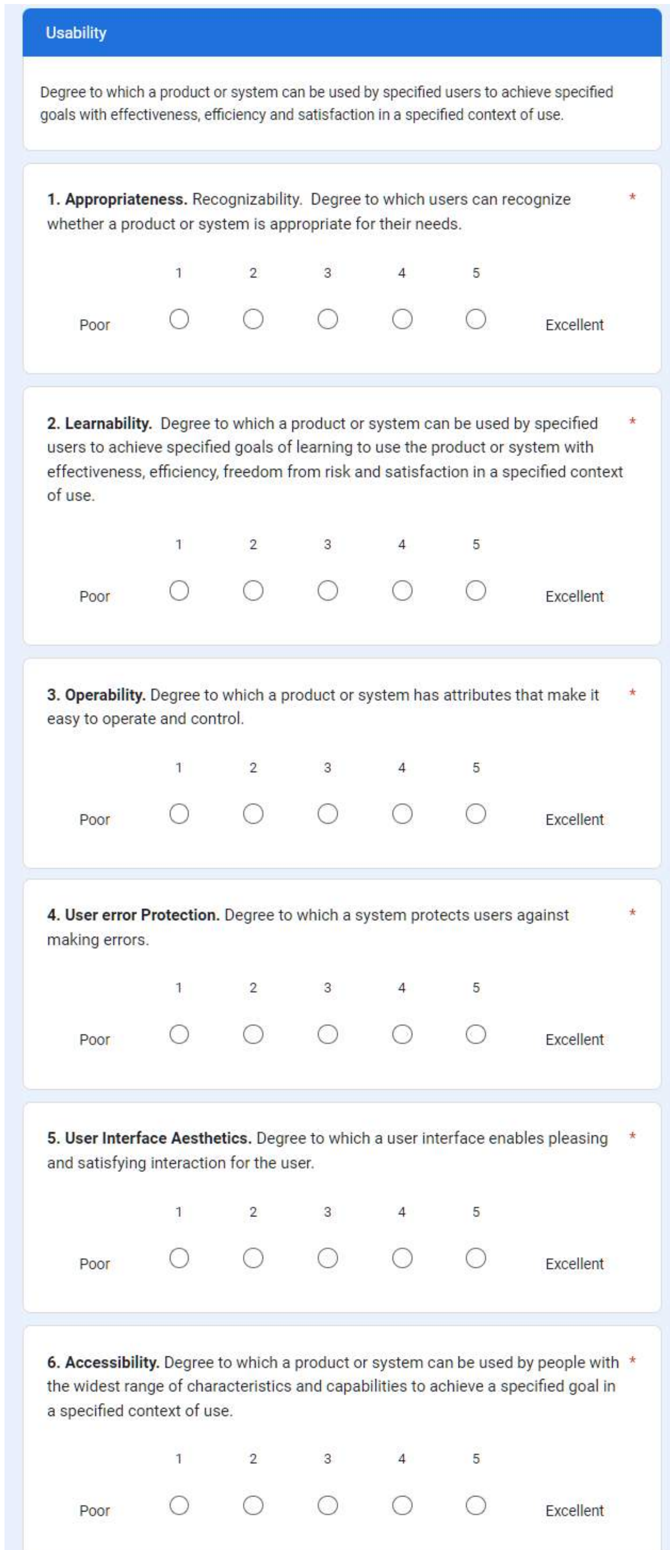
Degree to which a product, system or component can exchange information with other products, systems or components, and/or perform its required functions, while sharing the same hardware or software environment.

1. Co-existence. Degree to which a product can perform its required functions efficiently while sharing a common environment and resources with other products, without detrimental impact on any other product. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

2. Interoperability. Degree to which two or more systems, products or components can exchange information and use information that has been exchange. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent



Usability

Degree to which a product or system can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

1. Appropriateness. Recognizability. Degree to which users can recognize whether a product or system is appropriate for their needs. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

2. Learnability. Degree to which a product or system can be used by specified users to achieve specified goals of learning to use the product or system with effectiveness, efficiency, freedom from risk and satisfaction in a specified context of use. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

3. Operability. Degree to which a product or system has attributes that make it easy to operate and control. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

4. User error Protection. Degree to which a system protects users against making errors. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

5. User Interface Aesthetics. Degree to which a user interface enables pleasing and satisfying interaction for the user. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

6. Accessibility. Degree to which a product or system can be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

Security

Degree to which a product or system protects information and data so that the persons or other products or systems have the degree of data access appropriate to their types and levels of authorization.

1. Confidentiality. Degree to which a product or system ensures the data are accessible only to those authorized to have access. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

2. Integrity. Degree to which a system, product or component prevents an authorize access to, or modification of, computer programs or data.

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

3. Non-repudiation. Degree to which actions or events can be proven to have taken place, so that the events or actions cannot be repudiated later. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

4. Accountability. Degree to which the action of an entity can be traced uniquely to the entity. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

Reliability

Degree to which a system, product or component performs specified functions under specified conditions for a specified period of time.

1. Maturity. Degree to which a system, product or component meets needs for reliability under normal operation. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

2. Availability. Degree to which a system, product or component is operational and accessible when required for use. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

3. Fault Tolerance. Degree to which a system, product or component operates as intended despite the presence of hardware or software faults. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

4. Recoverability. Degree to which, in the event of an interruption or a failure, a product or system can recover the data directly affected and re-establish the desired state of the system. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

Maintainability

Degree of effectiveness and efficiency with which a product or system can be modified by the intended maintainers.

1. Modularity. Degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

2. Reusability. Degree to which an asset can be used in more than one system, or in building other assets. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

3. Analyzability. Degree of effectiveness and efficiency with which it is possible to assess the impact on a product or system of an intended change to one or more of its parts, or to diagnose a product for deficiencies or causes of failures, or to identify parts to be modified. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

4. Modifiability. Degree to which a product or system can be effectively and efficiency modified without introducing defects or degrading existing product quality. *

	1	2	3	4	5	
Power	◯	◯	◯	◯	◯	Excellent

5. Testability. Degree of effectiveness and efficiency with which test criteria can be established for a system, product or component and test can be performed to determine whether those criteria have been met. *

	1	2	3	4	5	
Poor	◯	◯	◯	◯	◯	Excellent

Portability

Degree of effectiveness and efficiency with which a system, product or component can be transferred from one hardware, software or other operational or usage environment to another.

1. Adaptability. Degree to which a product or system can be effectively and efficiently be adapted for different or evolving hardware, software or operational or usage environment *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

2. Installability. Degree of effectiveness and efficiency with which a product or system can be successfully installed and/or uninstalled in a specified environment. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

3. Replaceability. Degree to which a product can replace another specified software product for the same purpose in the same environment. *

	1	2	3	4	5	
Poor	○	○	○	○	○	Excellent

Further Feedback

🙏 Thank you so much for participating in our evaluation!

Recommendation/Comments/Suggestions *
*

Your answer

Appendix O - Results: SMAPE Table

Diff i = |Ground Angle i - Predicted Angle i| ; i = 1,2,3

Diff 1	Diff 2	Diff 3	Numerator	Denominator	Difference * 100
2.1350	0.9018	0.1571	3.1938	197.0843	1.6205
0.2684	2.6053	0.7501	3.6238	156.8742	2.3100
2.0736	0.0480	2.3950	4.5165	100.8663	4.4778
1.1415	7.5451	0.3373	9.0239	189.0171	4.7741
0.9524	0.7166	6.5870	8.2561	172.7080	4.7804
2.2088	9.2856	17.5914	29.0858	181.7100	16.0067
5.1487	6.2099	4.7193	16.0780	190.9559	8.4197
2.1523	3.1154	0.4786	5.7463	197.6405	2.9075
12.4720	1.1629	16.9010	30.5360	127.9080	23.8734
4.5262	4.4640	0.0432	9.0333	199.6969	4.5235
0.4300	1.2888	1.6180	3.3368	100.8872	3.3074
0.1964	6.6304	0.5332	7.3599	266.4336	2.7624
5.6445	6.5263	7.4513	19.6222	287.8204	6.8175
1.9021	2.3181	1.7051	5.9252	152.7171	3.8799
1.0897	2.4482	4.6368	8.1747	173.1667	4.7207
3.9633	4.0090	6.7349	14.7072	197.7952	7.4356
6.8544	2.0318	8.2810	17.1673	191.8353	8.9490
7.2941	7.1075	3.4302	17.8318	198.4878	8.9838
1.2388	3.9426	2.2915	7.4730	91.1860	8.1953
2.5142	0.8489	0.3948	3.7579	91.2871	4.1166
0.1162	3.7745	2.1284	6.0191	223.5101	2.6930
5.1573	1.5378	2.1204	8.8155	155.4375	5.6714
2.2111	1.9737	1.0134	5.1982	162.6453	3.1960
2.7303	3.3568	1.1990	7.2861	160.9021	4.5283
5.5694	4.9040	5.5298	16.0031	141.8031	11.2854
0.9292	1.5099	0.7716	3.2107	45.6503	7.0333

0.8167	1.5684	0.5533	2.9384	48.0746	6.1121
4.5676	0.8349	2.4767	7.8792	41.3131	19.0719
2.2958	3.6764	3.4468	9.4189	55.0447	17.1114
1.3998	2.4518	3.7800	7.6315	212.8976	3.5846
0.6882	0.3020	2.0192	3.0094	225.7614	1.3330
7.8402	1.9789	9.5981	19.4173	233.8198	8.3044
2.9482	2.1737	1.8319	6.9537	217.5164	3.1969
1.0860	1.1172	6.0512	8.2544	152.2189	5.4227
0.4355	0.8155	18.0856	19.3366	217.9356	8.8726
4.0974	3.3044	7.7101	15.1120	250.2072	6.0398
2.3893	2.4141	1.0102	5.8137	105.1465	5.5292
20.0460	14.4150	6.3951	40.8561	136.9021	29.8433
2.3225	13.6146	0.2575	16.1946	51.8938	31.2072
3.8745	2.5711	1.9516	8.3973	59.2463	14.1735
0.1324	1.9485	2.8517	4.9326	53.3707	9.2421
0.9051	1.1839	4.4919	6.5809	203.6407	3.2316
2.6493	0.7655	6.8620	10.2768	197.8632	5.1939
2.7349	5.0882	5.0698	12.8929	221.2328	5.8278
16.0845	22.0664	2.3690	40.5199	87.4409	46.3397
0.8604	0.1774	1.6987	2.7364	132.1931	2.0700
5.8795	2.3009	1.4123	9.5928	257.2058	3.7296
3.0116	15.2433	15.2887	33.5436	149.7558	22.3988
1.9440	0.9957	3.0393	5.9791	217.7969	2.7453
2.0686	0.9709	4.0320	7.0715	217.9135	3.2451
2.0502	0.2408	4.6686	6.9595	232.7785	2.9898
4.6403	2.8486	1.6103	9.0992	272.7652	3.3359
2.8786	2.7426	5.1074	10.7286	241.4979	4.4425
0.6161	7.4956	1.8183	9.9300	287.9840	3.4481
0.1303	0.9947	2.0364	3.1614	131.5728	2.4028
3.9660	3.2671	1.3313	8.5644	167.1842	5.1227
1.7495	3.0806	0.0000	4.8301	156.6770	3.0828

3.1242	3.6086	22.1209	28.8537	194.3685	14.8448
4.2174	0.2009	5.7366	10.1548	37.4601	27.1084
5.2358	1.0395	0.9410	7.2163	103.0361	7.0037
0.0662	6.3489	6.6546	13.0697	106.7259	12.2461
7.8895	4.7118	0.3931	12.9944	132.7688	9.7872
15.9128	15.9931	3.5302	35.4361	97.8079	36.2303
7.2479	3.9022	0.7966	11.9467	118.9023	10.0475
17.6390	16.2745	4.4473	38.3607	137.0387	27.9926
2.7305	2.8083	3.2172	8.7560	124.8560	7.0129
1.2894	3.9134	3.7649	8.9676	170.1552	5.2703
0.4854	2.0651	2.2236	4.7741	225.1149	2.1207
1.9152	3.5241	1.6045	7.0438	255.1944	2.7602
1.7998	12.5134	6.6521	20.9653	247.6275	8.4665
3.8319	3.3190	3.6441	10.7949	231.5828	4.6614
5.3780	2.1656	1.9209	9.4645	247.7755	3.8198
1.3263	2.5148	0.4132	4.2543	106.9863	3.9765
3.5125	1.3242	0.0000	4.8367	105.7117	4.5753
3.7071	1.1093	0.5795	5.3959	97.8118	5.5166
0.9005	4.8322	2.0660	7.7986	187.6037	4.1570
1.6036	10.5415	3.4272	15.5722	234.6248	6.6371
2.3949	13.9233	5.6333	21.9515	241.8975	9.0747
7.3263	5.9721	2.4139	15.7123	215.3357	7.2967
1.0820	3.4438	3.8550	8.3808	278.2008	3.0125
5.6208	6.4961	1.4027	13.5195	181.6655	7.4420
0.1407	2.8849	23.1024	26.1280	145.7582	17.9255
7.0503	8.7440	0.0000	15.7943	119.4617	13.2212
4.1739	5.5889	8.0914	17.8542	134.6324	13.2615
12.3011	7.9735	10.4429	30.7176	167.3564	18.3546
6.0664	8.9840	1.2061	16.2565	168.6869	9.6371
7.2731	2.9612	0.5422	10.7765	175.2717	6.1485
0.9324	2.1100	4.5634	7.6058	146.4398	5.1938

0.1301	14.7491	27.6064	42.4855	165.0106	25.7472
0.8739	4.7467	1.7353	7.3559	137.9107	5.3338
1.0657	2.0843	1.7852	4.9351	130.2251	3.7897
1.3572	7.8085	3.2431	12.4089	55.3345	22.4252
0.8419	0.7911	2.7504	4.3833	59.8916	7.3188
0.3905	0.9250	0.9310	2.2465	143.1935	1.5689
0.8010	1.8395	2.1494	4.7899	111.0041	4.3150
4.0857	7.4327	0.2425	11.7609	123.9989	9.4847
3.0863	5.6719	5.3310	14.0891	116.1354	12.1316
1.8330	5.1114	2.8376	9.7820	121.3852	8.0586
3.4660	0.5436	0.2586	4.2682	123.7462	3.4492
1.3560	2.0735	0.3501	3.7795	143.3445	2.6367
1.5416	4.6566	4.2004	10.3986	168.0715	6.1870
2.6294	3.3012	0.5129	6.4435	182.1075	3.5383
4.2467	1.6970	1.4873	7.4310	194.6970	3.8167
0.4199	0.8320	8.0457	9.2976	65.3524	14.2269
6.5518	4.5284	14.1429	25.2230	111.2989	22.6624
5.7919	8.2691	1.3622	15.4231	104.7848	14.7188
5.3348	1.6507	9.6731	16.6586	149.9848	11.1069
0.2831	1.7873	0.4068	2.4771	92.7183	2.6716
0.9831	0.8799	2.9273	4.7903	74.4909	6.4308
4.5478	2.6900	0.2928	7.5306	145.6715	5.1695
5.4275	3.9823	4.4580	13.8677	138.7523	9.9946
3.1511	5.0117	3.0821	11.2448	134.1172	8.3843
0.4437	1.6754	0.3429	2.4620	134.0302	1.8369
5.6587	0.5013	9.1668	15.3268	184.1978	8.3209
1.6663	2.4539	5.5220	9.6422	172.2284	5.5985
6.1319	5.8399	2.6183	14.5901	184.9161	7.8901
0.4594	0.9061	4.8958	6.2613	40.1875	15.5803
1.1203	1.2074	5.0677	7.3954	29.9928	24.6571
4.2482	0.4269	29.8253	34.5004	240.9895	14.3161

4.6814	0.1583	2.0634	6.9031	217.3817	3.1756
3.6870	1.5545	0.6831	5.9246	244.0366	2.4277
0.9324	20.8080	23.7350	45.4754	187.9574	24.1945

Appendix P. Results: Evaluation Data for Keypoint RCNN Model

Epoch	loss_classifier	loss_box_reg	loss_keypoint	BBOX AP(IOU=0.50)	Keypoints AP(IOU=0.50)
0	0.3556	0.7127	5.9208	0.327	0.002
1	0.2754	0.6432	5.5314	0.77	0.032
2	0.2376	0.5121	5.3047	0.915	0.139
3	0.195	0.4553	4.86	0.913	0.262
4	0.1857	0.4264	4.896	0.935	0.485
5	0.1674	0.3805	4.6665	0.927	0.203
6	0.1657	0.3696	4.5587	0.938	0.404
7	0.1905	0.375	4.4888	0.932	0.362
8	0.1651	0.3605	4.542	0.928	0.266
9	0.1462	0.3429	4.4181	0.94	0.504
10	0.1786	0.3891	4.6064	0.938	0.617
11	0.1899	0.4069	4.76	0.938	0.604
12	0.182	0.4124	4.7592	0.93	0.396
13	0.1502	0.3573	4.492	0.931	0.422
14	0.161	0.3576	4.4509	0.94	0.645
15	0.1444	0.3211	4.2944	0.944	0.595
16	0.1306	0.2915	4.2016	0.943	0.667
17	0.1319	0.2984	4.1903	0.941	0.603
18	0.1395	0.2884	4.0875	0.931	0.402
19	0.133	0.2899	4.1619	0.932	0.453
20	0.1483	0.3192	4.3011	0.936	0.511
21	0.1372	0.3166	4.271	0.943	0.575
22	0.1454	0.3124	4.2712	0.935	0.589
23	0.1277	0.2714	4.151	0.934	0.502
24	0.1336	0.3014	4.1724	0.937	0.515
25	0.1097	0.224	3.9103	0.939	0.547
26	0.1029	0.2303	3.7673	0.934	0.492
27	0.1087	0.2208	3.6117	0.932	0.375
28	0.1	0.2118	3.7088	0.932	0.623

29	0.0917	0.2023	3.555	0.941	0.575
30	0.0957	0.2002	3.4531	0.934	0.58
31	0.0881	0.1805	3.3133	0.933	0.533
32	0.0899	0.1684	3.1803	0.933	0.528
33	0.0877	0.1709	3.1946	0.933	0.561
34	0.0916	0.1824	3.279	0.933	0.553
35	0.0921	0.1761	3.1131	0.934	0.582
36	0.0834	0.1683	3.0718	0.933	0.58
37	0.0838	0.164	2.9823	0.933	0.579
38	0.0838	0.1598	3.0261	0.933	0.562
39	0.0902	0.1669	3.0368	0.933	0.563
40	0.0854	0.1566	2.9123	0.933	0.566
41	0.084	0.1611	2.9489	0.933	0.568
42	0.0792	0.1618	2.9338	0.933	0.564
43	0.0833	0.1594	2.9798	0.933	0.554
44	0.0956	0.1629	3.0124	0.933	0.561
45	0.089	0.1595	3.0887	0.933	0.565
46	0.0915	0.1684	2.9486	0.933	0.568
47	0.0885	0.1673	3.0023	0.933	0.577
48	0.0829	0.1676	2.9523	0.933	0.568
49	0.0831	0.1586	3.0149	0.933	0.569
50	0.0809	0.1607	2.9321	0.933	0.565
51	0.0828	0.1602	2.9169	0.933	0.566
52	0.0927	0.1728	3.0478	0.933	0.567
53	0.0821	0.1539	2.939	0.933	0.567
54	0.083	0.1594	2.9427	0.933	0.566
55	0.0771	0.1576	2.9308	0.933	0.566
56	0.0843	0.1623	2.8989	0.933	0.566
57	0.0852	0.1679	2.9944	0.933	0.566
58	0.0784	0.1526	2.8897	0.933	0.566
59	0.0859	0.1675	2.9996	0.933	0.566
60	0.0847	0.1614	2.9432	0.933	0.566
61	0.0798	0.161	3.0602	0.933	0.566
62	0.0788	0.1618	2.9348	0.933	0.566
63	0.0839	0.1577	2.971	0.933	0.566
64	0.0785	0.1657	2.9088	0.933	0.566

65	0.0803	0.1554	2.8604	0.933	0.566
66	0.0831	0.1713	2.972	0.933	0.566
67	0.0809	0.1562	2.9551	0.933	0.566
68	0.0888	0.1691	2.921	0.933	0.566
69	0.0854	0.1676	3.0188	0.933	0.566

Appendix Q - Results: ISO/IEC 25010 Evaluation

Respondent	Position
1	Radiology Resident
2	Radiology Resident
3	Radiology Resident
4	Consultant Radiologist
5	Radiologist
6	Physician
7	Radiologist

Characteristic	Respondent							Mean	Overall Mean
	1	2	3	4	5	6	7		
Functionality Stability									
1. Functional Completeness	5	5	4	3	5	4	5	4.428571429	4.380952381
2. Functional Correctness	5	4	4	3	4	5	5	4.285714286	
3. Functional Appropriateness	5	4	4	3	5	5	5	4.428571429	
Performance Efficiency									
1. Time Behavior	5	5	4	3	5	5	5	4.571428571	4.380952381
2. Resource Utilization	5	5	4	3	5	5	4	4.428571429	
3. Capacity	5	4	4	3	4	5	4	4.142857143	

Compatibility									
1. Co-existence	5	5	4	2	5	5	5	4.428571429	4.285714286
2. Interoperability	5	4	4	3	5	4	4	4.142857143	
Usability									
1. Appropriateness	5	5	4	2	5	5	5	4.428571429	4.261904762
2. Learnability	5	5	4	2	4	5	4	4.142857143	
3. Operability	5	5	4	2	4	5	4	4.142857143	
4. User Error Protection	4	4	4	2	4	5	5	4	
5. User Interface Aesthetics	5	5	4	3	5	5	5	4.571428571	
6. Accessibility	5	4	4	3	5	5	4	4.285714286	
Security									
1. Confidentiality	5	5	4	3	5	5	5	4.571428571	4.464285714
2. Integrity	5	5	4	3	5	5	5	4.571428571	
3. Non-repudiation	5	4	4	3	5	5	5	4.428571429	
4. Accountability	5	4	4	2	5	5	5	4.285714286	
Reliability									
1. Maturity	5	5	4	2	4	5	3	4	4.25
2. Availability	5	5	4	3	5	5	5	4.571428571	
3. Fault Tolerance	5	4	4	3	4	5	4	4.142857143	
4. Recoverability	5	4	4	3	5	5	4	4.285714286	
Maintability									
1. Modularity	5	5	4	3	5	5	5	4.571428571	4.542857143

2. Reusability	5	5	4	3	5	5	5	4.571428571	
3. Analyzability	5	5	4	3	5	5	5	4.571428571	
4. Modifiability	5	5	4	3	5	5	5	4.571428571	
5. Testability	5	5	4	3	4	5	5	4.428571429	
Portability									
1. Adaptability	5	5	4	3	5	5	5	4.571428571	
2. Installability	5	5	4	3	5	5	5	4.571428571	4.523809524
3. Replaceability	5	5	4	3	4	5	5	4.428571429	
OVERALL									**4.386309524**

Appendix R - Disclaimer

Disclaimer

This software project and its corresponding documentation entitled "ScolioVis: Automated Cobb Angle Measurement on Anterior-Posterior Spine X-Rays using Multi-Instance Keypoint Detection with Keypoint RCNN" is submitted to the College of Information and Communications Technology, West Visayas State University, in partial fulfillment of the requirements for the degree, Bachelor of Science in Computer Science. It is the product of our own work, except for the utilization of the Spine Web Dataset 16: 609 spinal anterior-posterior x-ray images and the Keypoint RCNN model on PyTorch.

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