Exploring a Novel Use of Artificial Intelligence to Detect Anatomical Landmarks on Lateral Cephalograms

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ABSTRACT

Objective: Lateral cephalograms are a type of radiograph used in orthodontic treatment to evaluate the structure of each patient's facial and dental anatomy. This project explores a novel use of artificial intelligence (AI) to identify anatomical landmarks on lateral cephalograms.
Methods: 2,500 lateral cephalograms were collected from the orthodontics clinic at UCONN Health. Trained orthodontists manually labelled each radiograph, plotting 27 different anatomical landmarks on each radiograph. The radiographs were inputted into an algorithm that was built using a convolutional neural network (CNN). The algorithm was adjusted several times to account for any errors before inputting the next set of radiographic images to be labelled. We compared the landmarks outputted by each version of the algorithm to the landmarks manually labelled by the experts.
Results: Each subsequent version of the algorithm proved to progress closer in accuracy to the landmarks plotted by orthodontic experts. As the algorithm was adjusted to account for its errors, the margin of error decreased for each of the 27 landmarks.
Conclusions: This exploratory project demonstrates the potential for machine-learning based classification algorithms to be used in real-world medical contexts, and specifically within the field of orthodontics for analyzing a lateral cephalogram.
Future Directions: Adding more radiographs to increase the sample size will help the machine plot the landmarks with greater accuracy. While this project only analyzed samples from one center, we have already begun collecting samples from other orthodontic practices to increase variation and sample size and thus improve the model in the next phase of this project. Normalization of the pixel-units currently used for error measurement into precise millimeter terms will be an important milestone in developing this technology to a standard fit for medical use.

BACKGROUND

Cephalometric x-rays (lateral cephalograms) are an important aspect of orthodontic diagnosis and treatment, and provide information pertaining to the dental, skeletal, and soft tissue parameters of each patient.[1] In orthodontic treatment, there are 27 anatomical landmarks that are plotted and used to make angular measurements which guide both treatment planning and diagnosis. A Convolutional Neural Network (CNN) is a type of machine learning model often used in image recognition contexts. When given an input image, this model can be used to detect probable objects within the image as well as their respective locations. Modeled after the neural network of the human brain, this form of machine learning uses layered abstraction to extract complex patterns from otherwise arbitrary visual inputs.

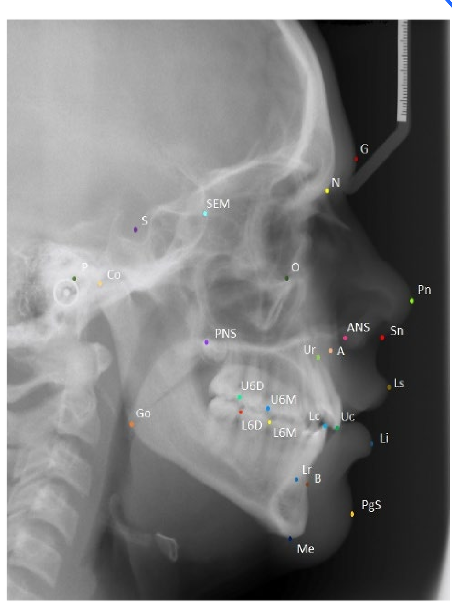

Figure 1: A sample cephalometric X-ray showing the 27 anatomical landmarks that are typically plotted on lateral cephalograms for orthodontic treatment.

Model Architecture

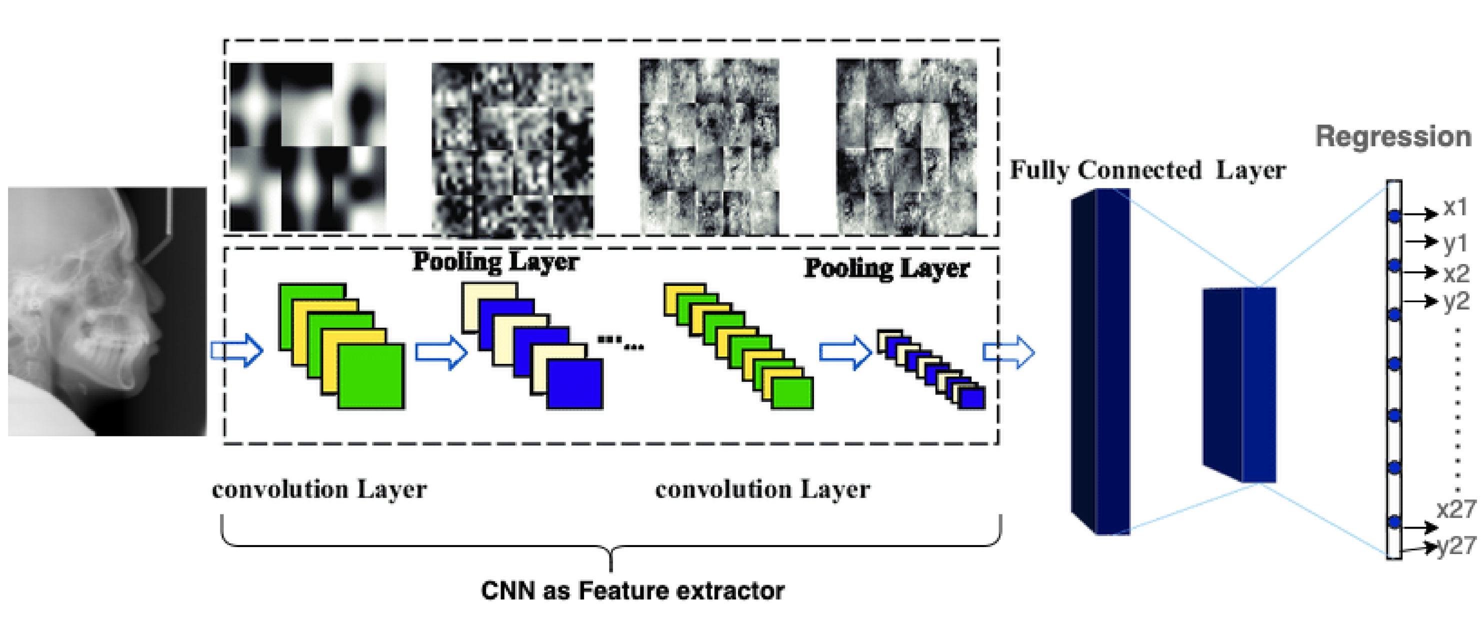

Figure 2: Schematic of the convolutional neural network (CNN) model with an added classifier layer.

METHOD AND MATERIALS

1. 2,500 de-identified lateral cephalograms were collected from the orthodontics clinic at UConn Health. An expert orthodontist (MU) manually labelled each cephalogram, and these labelled radiographs were used as the training data from the subsequent machine learning.
2. A computer scientist (GS) designed a CNN model to predict the landmarks on lateral cephalograms. Lateral cephalograms were inputted into the algorithm which plotted predicted landmarks based on the visual data. The model was then refined through data augmentation before inputting the subsequent set of radiographs. This data augmentation process was repeated several times, producing different versions of the model with each version slightly tweaked to improve upon its prior errors.
3. The base (original) model's predictions were compared to the predictions of the improved model. These were also compared to the anatomical landmarks labelled by expert orthodontists.
4. Adjustments of this model are ongoing as further samples continue to be processed for this study.

METHODS AND MATERIALS CONT.

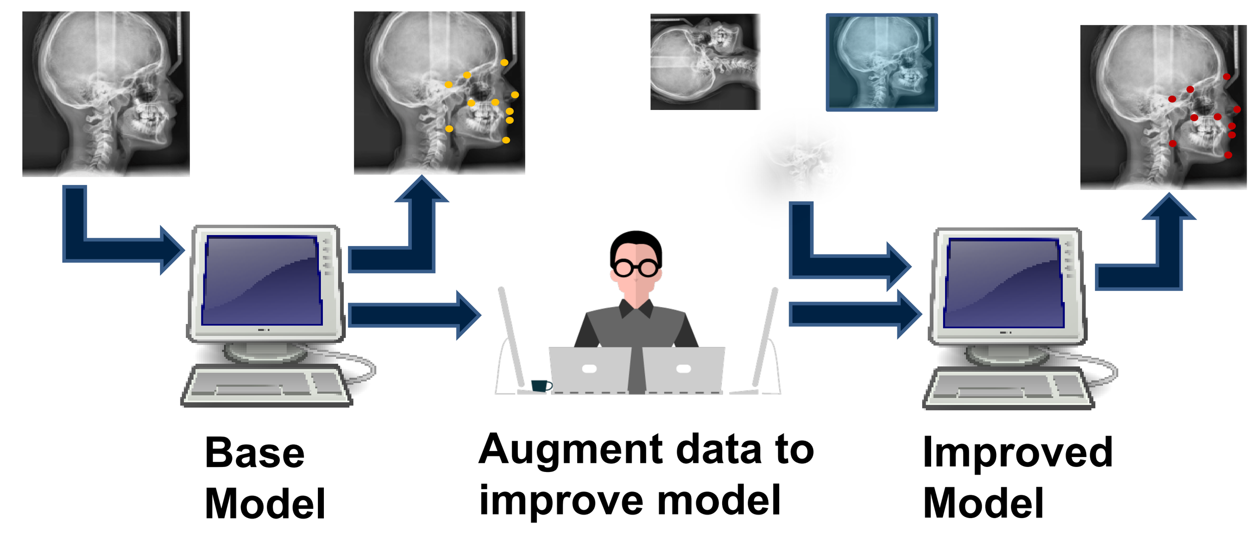

Figure 3: Schematic of the workflow used to improve the model after each set of inputs.

RESULTS

The basis for a successful model in this study is one whose predictions of landmarks have minimal, and medically acceptable error, compared to the expertly labelled landmarks. In this context, error is defined as the number of pixels between the machine prediction versus the true positions of the landmarks, relative to the overall number of pixels in the width and height of the image. The landmarks plotted by expert orthodontists are the "true" annotation, while the landmarks plotted by the machine are predictions of these true locations. The base model had a root mean squared error (RMSE) of 1.2% in accurately predicting the locations of the landmarks. The improved model has an RMSE of 0.9%. This represents a 25% improvement from the base model to the improved model.

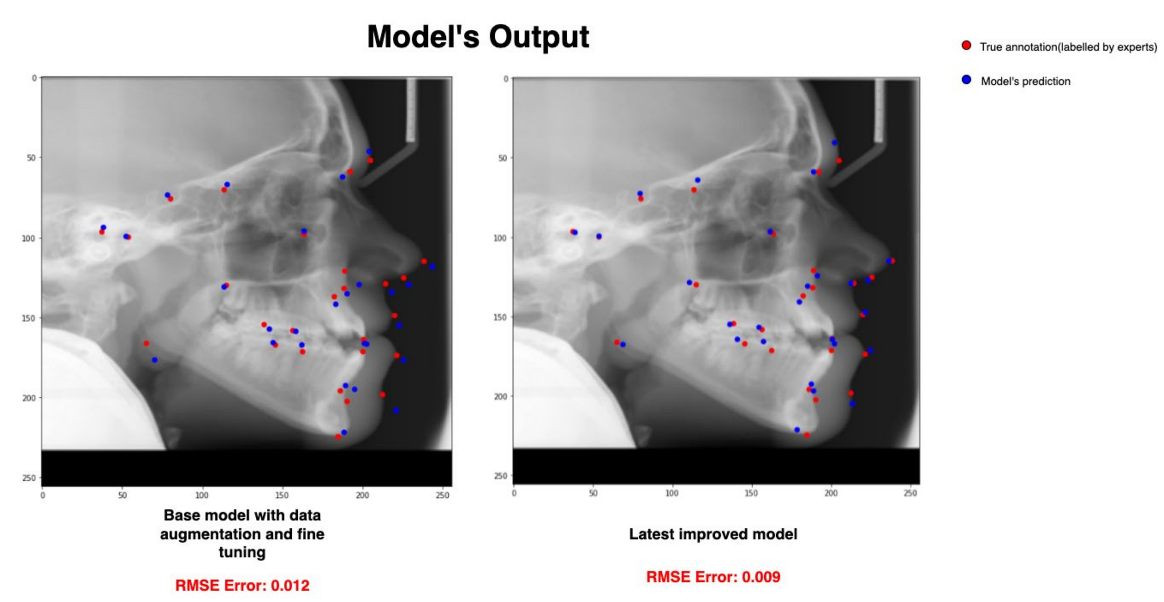

Figure 4: A comparison of the base model's predictions to the true landmarks (left image) and a comparison of the improved model's predictions to the true landmarks (right image).

The histogram below illustrates the distribution of the error for each individual prediction made by the latest model. The mean error was 1.72 pixels with a standard deviation of 1.67 pixels. Critically, as shown, these points are highly concentrated toward the left-hand side of the chart, which is a byproduct of selecting RMSE as the error metric when training this algorithm. This is important for any application of AI within a medical context, because minor inaccuracies in prediction are significantly more acceptable than even one major misprediction.

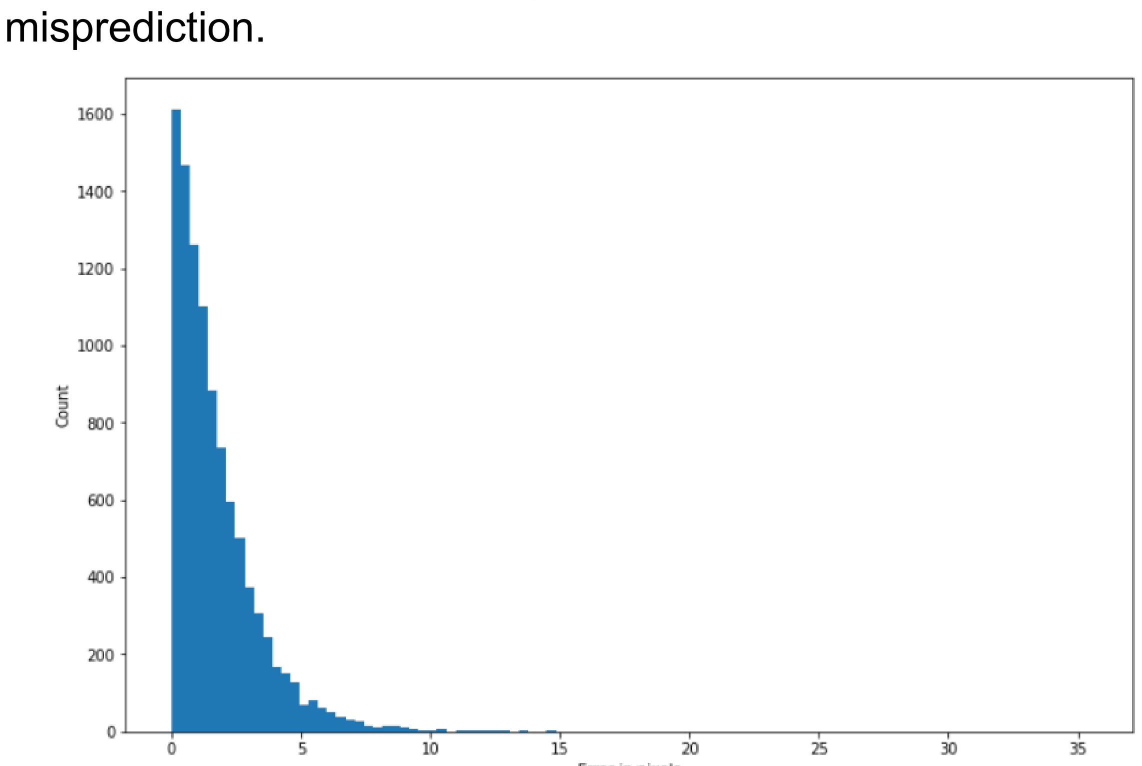

Figure 5: A histogram illustrating the total number of coordinates and their margins of error.

CONCLUSION

Plotting landmarks on lateral cephalograms is a significant source of time expenditure among orthodontists. A practical AI solution to automate or assist with the identification of these landmarks would represent the potential for significant efficiency gains within the field of orthodontics. Although the model is still being improved, these preliminary findings showcase the promising potential for machine learning to solve for this problem.

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