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Age Estimation: A Dual Pipeline For Teeth Detection And Apex-Height Measurement Using The Cameriere's Method

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The existing work presents a novel approach that combines Cameriere's approach with techniques from machine learning to obtain even better performance and minimize observer variation. This approach also entails the use of two actual real-time object detection model networks. The first model is concerned with detection and outline of specific teeth that would be useful for the analysis, thus, minimizing the role of selection of specific teeth manually. The second model makes accurate measurements of the apices and heights of the bicuspid and molar teeth, which are essential metrics in Cameriere's method. This dual-model strategy of attempting to automate the selection and measurement reduces bias and variability of the observer that are commonly associated with visually estimating the number of teeth and overall dimension. By using these two connected models, the general scenario of the interpretation of x-ray images is entirely covered, thereby offering better measurements both of the apex distance and height of the teeth. This combined machine learning approach improves the accuracy and may have implications in forensic anthropology, pediatric dentistry, and periodontology as a tool for child age estimation that may contribute to the better clinical and legal decision-making.

KEYWORDS: Age Estimation, Children, Cameriere's Method, Dental Development, Chronological Age, Machine Learning, Forensic Applications, Clinical Applications, Comparative Analysis, Data Collection, Accuracy and Reliability, Computational Techniques, Age Assessment.

1) Introduction:

The ability to estimate age, especially in children, is highly valuable in forensic science, physical anthropology, and clinical medicine. Age estimation in children has traditionally been carried out manually, with a focus on dental age since it reflects chronological age. Of the earlier six methods, the Cameriere's method is relatively more accredited and confirmed, employing key aspects of dental development to forecast age with great accuracy based on the size and shape of apices.

Advancements in deep learning and image analysis have created new opportunities for automated age estimation with less human intervention. In this regard, convolutional neural networks (CNNs) are deemed effective when dealing with medical images, including dental X-ray images. The YOLOv8 model is fast and suitable for tasks requiring high localization accuracy. This work describes a novel method based on the Cameriere's method integrated with twin YOLOv8 models to perform age estimation more effectively and with less reliance on human supervision. The first model identifies the teeth of interest, while the second extracts feature such as the apices and the total length of the tooth, which can be used in Cameriere's method calculations. Thus, the proposed dual-model pipeline provides better predictions of age in children compared to traditional subjective methods that typically rely on laborious manual assessments for forensic and medical purposes.

2) Literature Survey:

(a) Related Work

In paper [1] st This study applies computer vision techniques to estimate dental age using the lower third right molar in panoramic X-ray images. Two statistical models, Active Shape Model (ASM) and Active Appearance Model (AAM), are utilized. Both models use the shape and appearance of the tooth to find its outer contour, differing in how appearance is incorporated. These models extract features from the selected tooth, which are then input into a neural network for age estimation. A custom dataset of X-ray images with known ages was created, and manual segmentation of the tooth was done for each training image. The outer contours obtained were used to train both models, yielding promising preliminary results.

In paper [2] nd This research explores various dental diagnostic methods to detect anomalies and structural changes in teeth. Automated dental identification, which involves categorizing teeth into molars, premolars, canines, and incisors, is challenging. Effective identification requires understanding tooth anatomy and recognizing missing teeth and gaps. Panoramic dental images display both upper and lower jaws, making it difficult to identify developmental anomalies, cavities, gaps, and broken teeth. Deep convolutional neural networks (CNNs) excel in complex tasks like medical diagnosis and image classification. This study reviews CNN-based methods for classifying teeth and anomalies in panoramic images, discussing associated challenges and evaluating the pros and cons of each method to achieve high accuracy in anomaly detection and classification.

In paper [3] rd Age estimation is critical in forensic science for personal identification. Dental characteristics from radiographs, being durable, are commonly used for this purpose. However, traditional methods are often complex, time-consuming, and reliant on manual estimation, which can be error-prone. This research introduces the DeepTooth model, based on EfficientNet, for estimating human age and gender from radiographic images. The study includes a classification model for gender determination, a regression model for age estimation, and three classification models for age estimation—one trained on both genders, and two trained separately on males and females. The regression model for age estimation trained on both genders achieved an RMSE of 2.26, while the gender-specific model averaged an RMSE of 4.74. For gender classification, the model achieved an accuracy of 70.32 percent, using the same backbone and data-splitting strategy.

In paper [4] th Chronological age estimation is crucial in clinical procedures, with teeth being reliable indicators. Traditional methods using orthopantomogram (OPG) images are time-consuming and subjective. They also depend on high-quality images without considering varying dental conditions. This study proposes two fully automatic methods for age estimation from OPG images. The first method, DANet, uses a sequential Convolutional Neural Network (CNN) to predict age. The second method, DASNet, adds a second CNN to predict sex, enhancing age prediction. Tested on 2289 OPG images of subjects aged 4.5 to 89.2 years, DASNet outperformed DANet, reducing median Error (E) and Absolute Error (AE) by about 4 months. DASNet showed decreased AE values with younger subjects, achieving a median AE of about 8 months for those under 15. Compared to manual methods, DASNet demonstrated fewer estimation errors, proving effective for accurately predicting chronological age, especially in young subjects with developing dentitions.

In paper [5] th Accurately predicting age is critical in forensic human identification to rebuild precise biological profiles. While living individuals easily measure their age via calendars, determining the exact age of a deceased person in a criminal case poses a challenge. Forensic scientists estimate age by comparing tooth development stages in X-rays to established dental growth norms. This paper introduces an age estimation system using a Convolutional Neural Network (CNN) to predict age groups accurately. The system employs the Inception-v3 architecture, trained on a dataset of 1404 dental X-ray images of Malaysian pre-teens. The model was trained on 60% of the data and tested on the remaining 40%. It achieved 82% accuracy, 78% precision, 76% recall, and a 77% f-measure. The study concludes that a large dataset is essential for training and testing to familiarize the model with tooth growth patterns by age group. It is also vital to exclude images of poor quality and those impacted by tooth growth-affecting illnesses.

In paper [6] th Age estimation from radiologic data is crucial in both clinical medicine and forensic applications for determining unknown chronological age or distinguishing minors from adults. This study introduces an automatic multi-factorial age estimation method using MRI data of the hand, clavicle, and teeth. Unlike traditional methods based solely on hand bones (valid up to 19 years), this approach extends the age range to 25 years by incorporating clavicle bones and wisdom teeth. Utilizing a deep convolutional neural network, trained on data from 322 subjects aged 13 to 25, the method achieves a mean absolute prediction error of 1.01±0.74 years. For majority age classification, a classifier derived from thresholding the regression-based predictor proves more effective than direct classification, particularly in

minimizing cases of minors being misclassified as adults. This method addresses the limitations of current forensic practices, such as reliance on ionizing radiation, subjective age quantification, and the lack of a standardized approach for integrating age-relevant information from multiple anatomical sites.

In paper [7] th Orthopantomograms, OPG are important in dental x-ray imaging diagnosis since there are many diseases that are hard to diagnose on simple visual examination. The approach of automation of the teeth extraction process is important in enhancing decision support systems for dentistry. However, the process of segmenting teeth out of the panoramic images remains a problem due to weak separations between teeth and neighbouring structures, and relatively poor quality of these images that often necessitate pre-processing. A technique for automatically extracting teeth from panoramic images using a new system based on evolutionary algorithms was proposed and included jaw extraction and the separation of the upper and lower jaws; a GA was also used to identify the valleys of the teeth gap. In this method 42 images were attempted and percentage of success observed was 81.14% in upper jaws and 73.63% in lower jaws. Although numerous studies have been performed to segment the teeth region, very little research has been completed with respect to separating the teeth region and most of the work that was done does not produce accurate results for the panorama images.

In paper [8] th This research work is aimed at object detection in computer vision which is very important to robotics, surveillance, and self-driving cars. It also describes the You Only Look Once (YOLO) method, which has recently become quite popular because of its high accuracy and real-time performance due to the developments of deep learning. The assessment of the multiple object detection in complexity real-world scenarios is conducted in the study whereby the performance of YOLO is compared with other best object detection approaches. The experimental outcome demonstrates that this proposed method is effective to provide accurate and real-time multi-object identification. Moreover, the calibration and optimization of different YOLO algorithms will be assessed on the performance of the detection which make us discover the pros and cons of different YOLO algorithms. The results can be viewed as a confirmation of potential for deep learning-based approaches, as controlled experiments with a real-world dataset and high real-world complexity demonstrate adequately high results for multi-object recognition with YOLO, underscoring the continued applicability of this algorithm in contemporary challenges of computer vision.

In paper [9] th The advances in computer vision, machine learning and other subfields of image processing have proved to be very beneficial to the medical imaging industry which has enabled people to increase their diagnostic precision as compared to the traditional manual process and yet the costs are very low. Dental X-ray diagnosis especially for diseases and abnormalities continues to be problematic as well as time consuming; the help of clinicians may be necessary in reviewing the images. This paper presents the new work of computerizing first-line assessment of patients' conditions from OPG X-rays with the help of sophisticated deep object detectors that have proven their efficiency in medical imaging. Through the comparison of typical object detection frameworks in the literature, the study further seeks to determine the best approach that can be used to accurately detect dental abnormalities in order to support the planning of treatment and minimize the dependence on conventional examination in dentistry.

In paper [10] th The present investigation compares several deep learning models in radiology imaging with a current emphasis on CNNs: AlexNet, VGG, ResNet, DenseNet, and U-Net. These models are fundamental for tasks, for example, cancer diagnosis, organ part division, and disease categorization. The results reveal that some structures are highly effective for specific purposes; ResNet performs detected tumors better than the others and U-Net is superior to SegNet in segmenting organs. By the application of transfer learning from ImageNet, the study achieved the use of ensemble method to integrate the results from various models which led to improved classification. In sum, this study focuses on the identification of appropriate and ideal deep learning methods in medical image analysis, and supports the improvement of diagnostic and therapeutic imaging approaches.
In paper [11] th This research employs generative deep learning to estimate dental growth in pediatric dentistry through panoramic radiography underutilized not only in the numerical analysis of dental growth but also in the generation of dynamic representations in tooth growth. To achieve this, we used StyleGAN-XL, which is a generative adversarial network, to produce fakes images depicting dental development stages of children. We had 8036 unaltered anonymous panoramic radiography obtained from patients who visited Osaka University Dental Hospital and they included all stages of demetax and conditions. Using the given primary/mixed dentition images and the resulting images of permanent dentition, we objectively produced the image of intermediate forms that demonstrated the picture of developmental changes. When comparing the StyleGAN-XL model's performance, Fréchet inception distance scores were used. Radial distribution inversion was performed in order to map real images into the model's latent space for inter enamel inter proximal tuning. Thus, the images reflected switching from primary to permanent dentition and were fairly similar to real developmental changes. This method is a huge improvement on traditional dental imaging and predictive analysis giving a new perspective for the dentist and patient to explore dental development. These observations indicate additional areas of using generative models in medical imaging beyond the incumbent tasks of enhancement and modeling. The current research sheds light on the possibility of GANs to revolutionize medical imaging and offers future directions for the development of predictive dentistry.

3) Overview of Methods

In this section, the semi-automatic mode for age estimation in children is detailed, based on the Cameriere's method and the YOLOv8 twin model for teeth detection and apex height estimation from X-rays.

Cameriere's Method:
The Cameriere's method is another form of technique employed in age estimation; it's more useful when it comes to teenagers. This technique determines the mesiodistal dimension at the level of the open apices of the seven permanent left mandibular teeth using the distance between the inner margin of the open apex and the total height of the tooth for age estimation. This makes this method especially relevant for capturing the diachronic changes in dental development phases, especially in the childhood period. We have considered this method to be highly reliable which has made it possible for it to be applied across different populations.

But the manual method of applying the Cameriere's index eats much time and is also labor intensive; it also entails some bias by individuals. The formula for the Cameriere's method is given as:

$$\mathbf{Age = 8.387 + 0.282\ g - 1.692\ *x_5 + 0.835\ N_0 - 0.116\ s - 0.139*\ s*N_0}$$

where g is a variable, 1 for males and 0 for females

x5= Normalized score of 2nd premolar

N0= Number of teeth with closed apex

s= The sum of the normalized scores of teeth with open root apices

Dual YOLOv8 Models:
Therefore, the semi-automated approach of this research establishes a dual YOLOv8 model in the flowchart for enhancing age estimation. The first model recognizes three primarily useful teeth within age estimation: they include the First Bicuspid, Second Bicuspid and the First Molar. Another model focuses on basic geometric properties, including the apices and total height of the teeth from images of the teeth we get from X-ray. This method decreases the level of intrusion into the processes of detection and measurement, the algorithm can detect the structures of teeth to promote calculation of age of the individual accurately.

Automated Pipeline: Thus, the integration of these models leads to an automatic pipeline which allows to extract the important features from the analysed X-ray images. In contrast to the age estimates obtained using a manual approach, which present considerable variability, the application of the dual-model approach improves age approximation in children. However, this approach also provides theoretical and application value which is consequential in forensic sciences and clinical medicine.

Semi-Automated Pipeline: This increased speed is made possible by a YOLOv8-based semi-automated system that can extract features from Xray images at a rate thirty-nine times faster than manual extractions. Here, it is crucial to note that manual review is still required for the final confirmation of results; however, this extent of semi-automation affords a substantial amount of time spent on manual calculations while diminishing intra-samples variability in predictions. As a result, the estimation process becomes more likely to be accurate, notably this is very important assuming it is applied in forensic or medical where accuracy is key and time is of essence. However, the proposed solution is only semi-automated and yields significantly less mistakes and faster outcomes than fully manual Cameriere's technique, based solely on observation.

4) Proposed Methodology

In this section, the approach to enhance age estimation in teenagers by combining the Cameriere's method with two YOLOv8 models created for teeth detection and apex-height estimation from the X-ray images is described. The approach proposed in this work aims at automating those steps in order to improve the key steps of the total process of assessing the age and make a much better estimate in terms of reliability.

A. Dual YOLOv8 Models

The methodology employs a dual YOLOv8 framework to effectively detect and measure essential dental features:

-Teeth Detection Model: The first YOLOv8 model is trained to predict which of these teeth are necessary for age estimation which are the First Bicuspid, Second Bicuspid, and the First Molar. Using high-quality dental X-ray images, this model identifies and labels these teeth as the key teeth necessary for dental analysis which requires accurate identification.

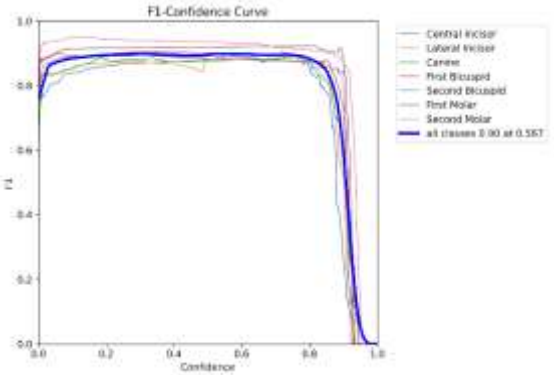

Figure 1: F1 to Confidence Curve Model 1

Figure 1 demonstrates that the more the confidence increases, the more the F1 score increases as well. This means that if your values of F1 is close to 1 and consistent for all the different levels of your confidence threshold it tells you that for most of your classes your model yields a good balance of precision and recall. It appears very robust and probably impenetrable at higher confidence bounds showing that the model should yield precise recall at all times.

-Apex and Height Measurement Model: The second, the YOLOv8, is designed to detect important topographical parameters, such as the apices and the height of the detected teeth. This model is particularly tailored for 'cone-beam' images that are required in the Cameriere's method of evaluating periodontal status. There are elements of the theory that are more significant than others in determining any difference in age estimation; the apices of the teeth and the tooth height.

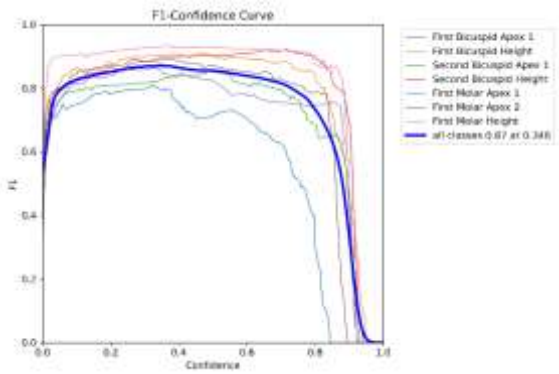

Figure 2: F1 and Confidence Curve Model 2

Figure 2 shows that with increasing for confidence levels, the F1 score increases as well. This means that whenever the F1-score is high, say 1 and has a similar value at the various confidence intervals then there is probably a good balance of Precision and Recall Scores for most of the classes. The sharpness of the model emergence of the above reveals the model to be rather reliable and robust at the higher levels of model confidence to show the dependence of recall accuracy.

B. Using of the Cameriere's Method

As soon as the teeth and features of the dental silhouette are identified, the Cameriere's method is performed. This technique measures the distance between the inner line of the open apices and the total height of the tooth and produces an index corresponding to person's chronological age. The combination of the YOLOv8 models in the automated measurements with this conventional method minimizes the recurrent variations and possible mistakes caused by manual estimations.

C. Performance evaluation metrics

For evaluating the performance of the dual YOLOv8 models and the entire age estimation, the study employs two significant quantitative measures, namely, MSE and RMSE. MSE is a measure of the average squatted deviations from the actual ages The chosen models are evaluated by calculating the MSE, indicating their accuracy. RMSE provides by definition an easily interpretable error measure with units of age and gives an idea of the variability of prediction errors. A lower value of both the parameters indicates better model performance and hence validates the utility of the proposed approach in estimating age from dental X-ray images.

5) Comparative Analysis

This section presents a comparative analysis of age estimation results obtained manually using the Cameriere's method and those generated through an automated process employing a dual YOLOv8-based model. The study aims to assess the accuracy and reliability of the automated method in comparison to the traditional manual approach for determining age in adolescent dental X-rays.

Crude Estimation of Age The manual age estimation method relies on visual inspection of dental characteristics, including the measurement of open apex distances and total tooth length of reference teeth. This process involves subjective interpretation, the use of calibrated tools,

and mathematical calculations based on the Cameriere's index. While this method has proven useful in clinical and forensic settings, it is prone to human error, including variation in interpretation and measurement inaccuracies.

On the contrary, the automated method integrates two YOLOv8 models: the first for detecting specific teeth, and the second for identifying anatomical landmarks like apices and tooth height. This automation significantly reduces human interference, providing more accurate and consistent age predictions by leveraging advanced object detection and edge detection techniques.

Evaluation Metrics: MSE and RMSE

To evaluate the performance of both methods, Mean Squared Error (MSE) and Root Mean Squared Error (RMSE) are used as key metrics:

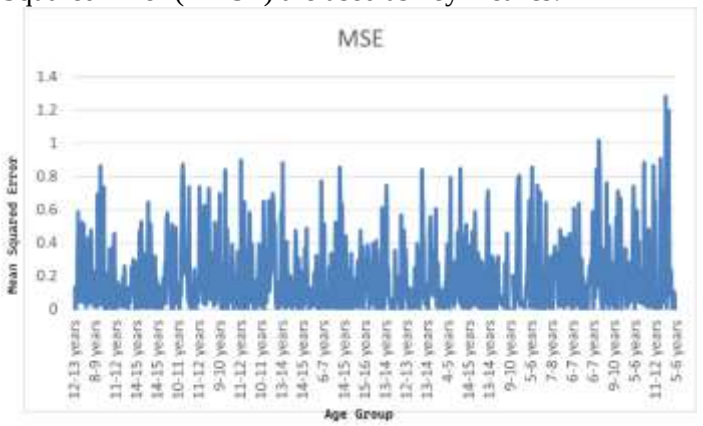

Figure 3:Mean Squared Error

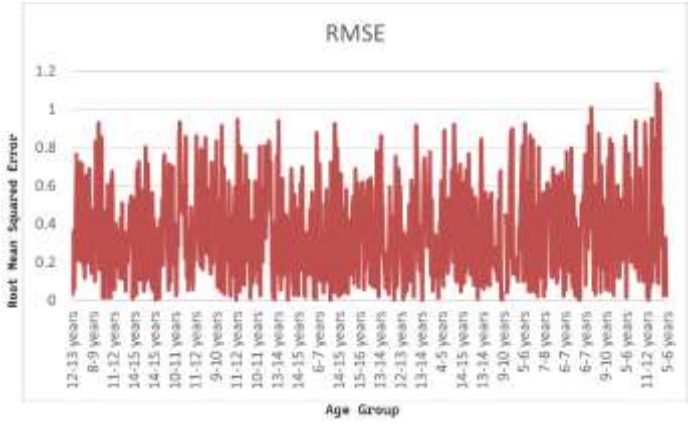

Figure 4: Root Mean Squared Error

6) Conclusion

In this paper, the author provides a comparative analysis of age estimation to introduce the conventional Cameriere's method and the developed dual YOLOv8 model. The manual

technique uses an ability to assess the dental features by look at them, which is one the most vulnerable because of the increased human impact. In contrast, the automated method employs two YOLOv8 models: A first one is used specifically for the detection of the teeth, while the second one measures the height of the apex, thus reducing the interference of human element. Statistical measures of the effectiveness of the proposed method are provided by calculating the Mean Squared Error (MSE) and the Root Mean of Squared Error (RMSE) whereby both the MSE and RMSE for the automated method demonstrated a value less than 1. The outcomes of the study show the effectiveness and reliability of the dual YOLOv8 model toward encouraging applied active Ml in clinical environments. This research suggests that it is possible to use automated approaches in clinical utility so as to increase accuracy and reliability of age predictions. Such methodologies help dentists and forensic specialists to enhance the assessment functions and increase accuracy of age identification. Lastly, the study contributes to the scientific community effort to advance the efficiency and accuracy of current and future automated age estimation in dentistry and forensic fields.

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