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3D Dental Biometrics: Transformer-based Dental Arch Extraction and Matching

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***Abstract*—**The dental arch is a significant anatomical feature that is crucial in assessing tooth arrangement and configuration and has a potential for human identification in biometrics and digital forensic dentistry. In a previous study, we proposed an auto pose-invariant arch feature extraction Radial Ray Algorithm (RRA) and a matching framework [1] based solely on 3D dental geometry. To enhance the identification accuracy and speed of our previous work, we propose in this study a transformer architecture that can extract dental keypoints by encoding both local and global features. The dental arch is then constructed through robust interpolation of the dental keypoints using B-Spline and is compared using the same identification framework. To evaluate the effectiveness of our proposed approach, we conducted experiments by matching the same 11 post-mortems (PM) samples against 200 antemortem (AM) samples. Our results show that our approach achieves higher accuracy and faster speed compared to our previous work. Specifically, 11 samples (100%) achieved a top 6.5% (13/200) accuracy out of the 200-rank list, compared to the top 15.5% (31/200) accuracy previously [1]. Additionally, the time required to identify a single subject from 200 subjects has been reduced from 5 minutes to 3 minutes. The dental arch can be used as a powerful filter feature. Our findings make a significant contribution to the existing literature on dental identification and demonstrate the potential practical applications of our approach in diverse fields such as biometrics, forensic dentistry, orthodontics, and anthropology.

Keywords*— *3D Dental Biometrics, Dental Arch, Keypoint Detection, Transformer, Human Identification

I. Introduction

Dental identification is an increasingly promising biometric strategy for human identification, particularly in tragic events such as homicides and mass disasters, due to the indestructible nature of dental records [1-3]. Current dental identification methods mostly rely on 2D radiographs which can be unreliable and inefficient [1-9]. We proposed 3D dental identification approaches that rely on matching 3D dental records [1, 10, 11] since 2011. The aim of this study is to improve our previous work [1] by achieving higher identification accuracy and faster identification speed.

II. Methodology

In this section, we present the details of our approach comprising mainly three modules: dental keypoint detection, dental arch construction, and efficient dental identification.

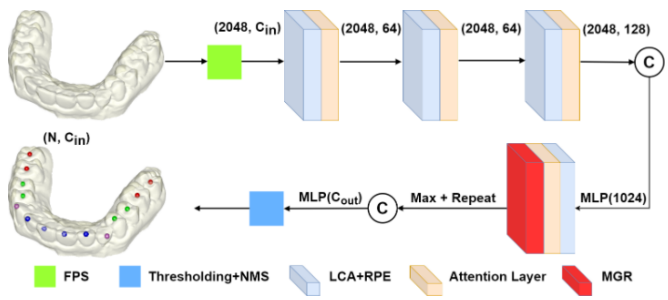

Fig. 1. Dental keypoint detection neural network

A. Dental Keypoint Detection

The success of dental arch construction hinges on the accurate detection of dental keypoints. To achieve this goal, we propose a transformer neural network architecture (Fig.1) that can effectively encode both local and global information, generating robust keypoints at the center of each tooth (Fig 2). However, due to the limited availability of dental samples, we rely on position embeddings to learn the accurate local geometry. Our approach is inspired by the 3D Medical Point Transformer [12], which enables the modeling of long-range dependencies of global contents via convolutional operations, as well as local context interactions based on lambda attention that has been modified with local context augmentation. Our architecture takes as input a dental model with N points and 6 C_{in} channels, where C_{in} includes coordinates (x, y, z) and normal vectors (nx, ny, nz). We sample 2048 points using the Farthest Point Sampling (FPS) algorithm and extract features using the LCA plus RPE layer, attention layer, and MGR layer. Further details on these layers are provided in [12]. We obtain a feature tensor of size 2048 by C_{out}, where C_{out} is set to 4 to accommodate four tooth categories: incisor, canine, molar, and premolar. We consider only points with probability above a threshold as keypoints, but multiple keypoints may cluster together. We address this issue using the Non-Maximum Suppression (NMS) algorithm, which removes non-maximum points and retains only one point with the highest probability as the final dental keypoint.

B. Dental Arch Construction

Now we are ready to construct the dental arch based on the detected keypoints. We employ B-spline interpolation to construct the arch. Fig. 2 (middle) shows the constructed dental arches for two input dental models. We can clearly see that the two arches differ from each other such that they can be used for human identification.

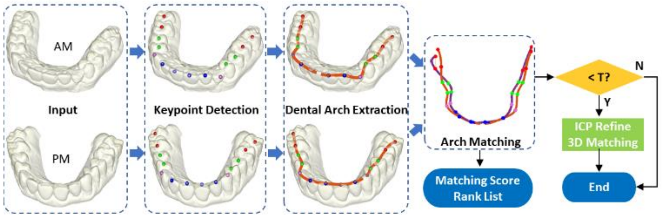

Fig. 2. Dental Arch Extraction and Matching

C. *Efficient 3D Dental Identification*

Our 3D dental identification framework (Fig.2) begins by detecting keypoints using our transformer architecture, followed by constructing dental arches and performing coarse arch matching. Dental samples can be identified through this step, with only low-scoring matches undergoing refinement through an Iterative Closest Point (ICP) algorithm [13] to produce the final result. This method significantly increases matching speed as most AM samples are filtered out during the coarse arch matching. This signifies the fact that the dental arch can be used as a powerful filter feature.

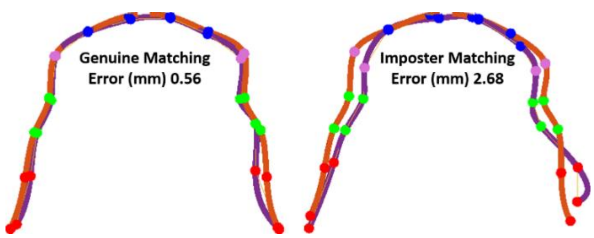

Fig. 3. Genuine arch matching error versus imposter arch matching error

III. Experiments

A. *Experimental Results*

TABLE I. Arch Matching Results

PM ID	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Rank	1	1	8	1	1	10	1	1	2	1	13

We used a dataset with 11 PM models and 200 AM models. The absolute matching rank in the 200-rank list is recorded for each PM sample in Table 1. 63.6%(7/11) of the PM samples achieved rank-1 (1/200) accuracy. 90.9% (10/11) achieved top 5% (10/200) accuracy, and all 11 samples (100%) achieved top 6.5% (13/200) accuracy. These results outperformed our previous results [1], where only 27.2% of the PM samples achieved rank-1 (1/200) accuracy, 72.7% achieved top 5% (10/200) accuracy. 90.9% achieved top 10% (20/200) accuracy and all 11 samples (100%) achieved only top 15.5% (31/200). Additionally, the time required to identify a single subject from 200 subjects has been reduced from 5 minutes to 3 minutes.

IV. Conclusion

In this study, in order to enhance the identification accuracy and speed of our previous work [1], we proposed a transformer architecture that can extract dental keypoints by encoding both local and global features. The dental arch is then constructed through robust interpolation of the dental keypoints using B-Spline. The identification is then accomplished by matching dental arches first and then matching the filtered 3D models instead of directly matching all the AM models. We have proved that the extracted dental arch can be used as a powerful filter feature in future studies. We have improved the identification accuracy for all the 11 PM samples from the top 15.5%(31/200) to the top 6.5%(13/200) out of the 200 rank list, while reducing the identification speed from 5 minutes to 3 minutes to identify 1 PM subject from 200 AM subjects. In contrast that our full-fine matching methods usually take about 45 mins [10-11]. Our findings make a significant contribution to the existing literature on dental identification and demonstrate the potential practical applications of our approach in diverse fields such as biometrics, forensic dentistry, orthodontics, and anthropology. Compared to our previous arch auto-extraction solely based on geometry [1], one disadvantage of this study is that the manual specification of the keypoints on dental surface is needed. And it's fairer to include the training time for comparison in the future.

Acknowledgments

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