A Novel Approach based on Image Processing in the Analysis of Human Dental Forensic

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ABSTRACT
Forensic Odontology is a study dedicated to identifying individuals based on specific characteristics of teeth structural arrangement. Human bite mark analysis is by far the most demanding and complicated part of forensic dentistry. This process generally involves human interaction and hence tends to bias. In this paper a system is tested and implemented that reduces human bias to certain extent. Each person has a unique dental arrangement which is exploited to identify an individual to the exclusion of all others. In this paper diverse approaches have been proposed for human bite mark identification and human dental radiograph identification. The experimental results clearly demonstrate that the approach significantly outperforms the existing ones in terms of execution time. The proposed method is also seen to be effective under a wide variety of imaging conditions.

General Terms
Image Processing, MATLAB.

Keywords
Bite mark identification, dental radiograph identification, image analysis, forensic dentistry, multidisciplinary approach.

1. INTRODUCTION
Forensic dentistry is a specialized field of dentistry which deals with bite mark analysis and identification, mass disaster victim identification, missing person databases and identification, and other legal issues [1]. The main purpose of forensic dentistry is to identify deceased individuals for whom other means of identification are difficult. For example, bite mark injuries are rarely accidental and are good indicators of genuine child abuse [2]. It has become a popular and effective method to identify victims in cases of mass disasters like floods, plane crashes etc. when other methods of identification (fingerprints, physical etc.) are not feasible, provided the dental database is available. Unlike other biometric characteristics (e.g., fingerprints, iris, etc.), dental identification is complicated by the fact that dental features do change over time [3]. In most known case of 9/11 attack, among 973 victims identified in the first year (with only one method), about 20% of victims were identified using dental records [4,5]. In a tiny state like Goa in India several cases of mutilated dead bodies are found which are beyond biometric identifiers like fingerprints and DNA and hence can be referred to forensics and there arises the need for study in this domain.

This paper is organized as follows: Section 2 gives short introduction to available methodologies in human bite mark identification and dental radiograph identification. Section 3 gives the approaches identified and implemented. Experimental results are presented in Section 4. Finally conclusion is drawn in section 5.

2. PRELIMINARIES
Firstly, preservation of bite mark evidences has received much attention. Several guidelines are available. The readers can have look at them in [6]. The collection of evidence in Bite mark cases falls into several categories [7]:

I. Description of bite mark(s)

II. Collection of evidence from the victim.

III. Collection of evidence from the suspect(s)

IV. Analysis of all evidence.

The two main approaches prominent to Forensic Odontology are Bite mark identification and Dental Radiograph identification. The literature survey traces the prominent work and their outcomes. The appearance of bite mark, their classification, degree of impression and human bite marks as psychological evidences are discussed in [8].

2.1 Human Bite Mark Identification HBMI
Various methods have been proposed for bite mark identification but most of them being manual and time consuming, apart from the fact that the final result lies on operator expertise. Flora et al (2009) has discussed various forensic bite mark identification using methods based on image processing [9]. Digital based approach can help to retrieve accurate evidence, leading to greater number of positive results [10],[11],[12]. The existing techniques for HBMI are presented below.

2.1.1 Matrix method
Bowers (1998) introduced the technique of Matrix method [1], wherein overlays generated are compared with the bite mark images using parameters such as area measurement in millimeters and centroid position in (x,y) coordinates[13].It is highly complex being manual and hence time consuming with inherent inconsistency.

2.1.2 Xerographic method
The technique of Xerographic method [1],[13] basically involves comparing the overlays generated with images of the bite mark directly by human inspection. The upper and lower study casts are placed on the glass plate of the photo copy

machine. It is then photocopied on an A4 sized plain white paper. A transparent sheet is then overlaid on the photocopy image and the outlines are traced. The overlay is then scanned and the image is saved as xerography overlay. This method was introduced by Daily JC which was published in the journal of forensic science Vol.3.This method is basically simple in nature but fully dependent on skill of the person involved, making the accuracy highly invariable and hence the test unreliable.

2.1.3 Using artificial neural networks

Mahasantipriya *et al* proposed bite mark identification using neural networks methodology. In this technique, each bite mark sample is transformed from bit depth of 32 to 8-bit gray scale, followed with stages like contrast limit adaptive histogram followed with median filter to enhance the tooth borders and several features like CC, I-LC angle, I-RC angle, curvature, ratio, HTT-D is computed. Gradient descending algorithm for adjusting weights and biased was employed in the training process with the help of Levenberg-Marquardt algorithm to provide the numerical solution [14].

2.2 Dental radiograph identification

It involves processing and matching of dental radiograph images. Given a dental record, usually a postmortem (PM) radiograph, there is need to search the database of ante-mortem (AM) radiographs to determine the identity of person associated with PM image.

2.2.1 Dental Charting method

This is one of the oldest methods for dental identification which involves comparing dental profiles of the given dentitions [1]. Dental profiles are dental charts which are completed by odontologists. The comparison thus involves preparing dental chart of the dentition in question, and comparing this chart with those in a database. The odontologists rejects or confirms the tentative identity depending on the number of feature matches [15],[16].

2.2.2 Using Radiographs

The prominent advantages of digital radiography are the immediate availability of the images, elimination of film development and processing. New digital X-ray systems and portable X-Ray tube heads allow Odontology teams to work directly at the site of mass fatalities [17]. This comparison too can lead to subjectivity.

3. PROPOSED IMPLEMENTATION

3.1 Human Bite Mark Identification HBMI

For Bite Mark identification normally forensic odontologists compare the bite mark image with an impression of the dentition it is to be compared with. These impressions are called as overlays. The details of which can be found in[10],[18]. What differs in most cases is the method of generating the overlays. Adobe Photoshop, a graphics editing programme was used to generate overlays. An ABFO No. 2 scale was placed at the lower left side of the cast to establish left laterality and ensure life sized regeneration. An image showing alongside ABFO scale no 2 is illustrated in figure 4. The detailed flowchart for bite mark identification is as shown in Fig 1.

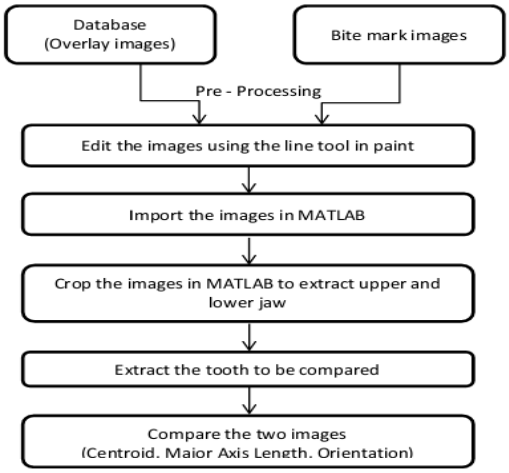

Fig 1: Flowchart for HBMI

3.1.1 Database formation and Processing

Database is derived from the overlay images. The database consists of selected overlay images which are distinct. The database processing involves the following four steps.

a. Overlay Processing
b. Logical Image conversion
c. Cropping of upper and lower jaw
d. Segmentation

The above steps are as shown in Fig 2.

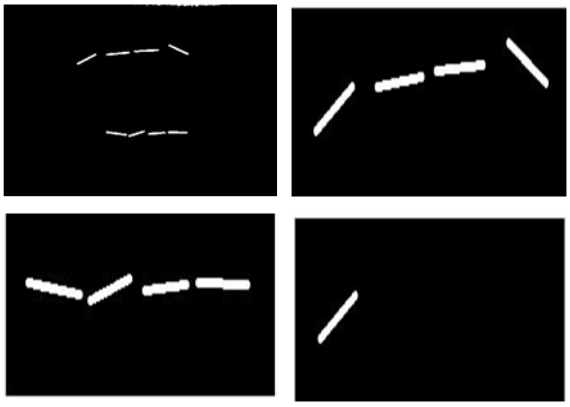

Fig 2: Database Processing steps (L-R,T-B)

3.1.2 Bite Mark Image Processing

Bite mark images are also first edited in MS Paint program to draw lines for each tooth from one edge to another as shown in Figure 3. The image appears to be flipped so as to properly match with the overlay image and to align with camera angle. Further processing steps are similar as discussed in 3.1.1 such as, Conversion to logical image, cropping into lower and upper jaws and segmentation.

The two counterpart images are compared on the basis of Centroid, Orientation of each tooth with respect to first tooth and length of each tooth. Centroid can be calculated using the following equation:

$$Cx = \frac{\int x \, dA}{A} \qquad \text{Eq. (i)}$$

$$Cy = \frac{\int y \, dA}{A} \qquad \text{Eq.(ii)}$$

where x = axis in the x-direction

y = axis in the y-direction

A = total area of the region

The orientation is calculated as shown in figure 4.

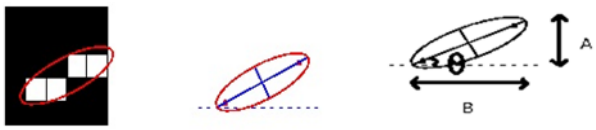

Fig 3: Images showing Orientation angle calculation

Orientation of the region is tabulated with respect to the horizontal axis and is calculated using

$$tan(\Theta) = \frac{A}{B} \qquad \text{Eq.(iii)}$$

where A: height from the horizontal axis

B: horizontal length between starting and ending point of the tooth.

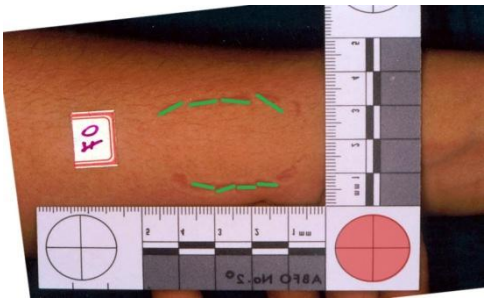

Fig 4: Image showing Bite mark alongside ABFO scale

3.2 Dental Radiograph identification

In this approach, given a post-mortem (PM) radiograph with a marked region of interest (ROI) the database of ante-mortem (AM) radiographs is searched to retrieve a closest match. The problem of creating post mortem identification system is addressed by matching image features extracted from dental radiographs.

3.2.1 Dental Radiograph Image Processing

The detailed algorithm for human dental radiograph identification has been listed as follows.

a) Tooth segmentation of ante mortem (AM) radiograph and post mortem (PM) radiograph is done.
b) The segmented tooth of AM and PM image is processed by finding the extreme points at all four corners and also the fifth point at the center of the roots.
c) Calculate the width at lower and upper end of the teeth.
d) Calculate the length at both the sides of teeth.
e) Calculate the average length to width ratio.
f) Find the root center angle by using the lower three points.
g) Perform the same steps for AM image.
h) Compare the AM and PM radiograph image using the two parameters root center angle and length to width ratio.

The segmented teeth and corner point detection is as shown in Figure 5.

Fig 5 : Image showing segmented teeth and corner point extraction alongside

3.2.2 Comparison between AM and PM images

The points to be detected as shown in Figure 5 are

(a) Upper right corner point (B1,B2).

(b) Upper left corner point (A1,A2).

(c) Lower right corner point (C1,C2).

(d) Lower left corner point (D1,D2).

(e) Root center point (E1,E2).

The AM and PM images are compared using the following parameters.

- Average vertical length:

The upper right corner point and lower right corner point is joined by line segment. Similarly the upper left corner point and lower left corner points are joined. The distance of each segment joining the two points is calculated as follows: If (A1, A2) and (D1, D2) are two upper and lower left corner points then the distance between them is given by formula

$$S1 = \sqrt{(C1 - B1)^2 + (C2 - B1)^2} \qquad \text{Eq.(iii)}$$

The average vertical length is the average of the two distances.

- Average horizontal length:

To find this length the distance between upper right and left corner is calculated and also the distance between the lower right and left corner point is calculated by formula

$$S2 = \sqrt{(B1 - A1)^2 + (B2 - A2)^2} \qquad \text{Eq.(iv)}$$

The average horizontal length is average between the two distances.

- Length to width ratio:

It is obtained by dividing the average vertical length to average horizontal length.

- Root Center Angle

To find the root center angle join the lower three points to form triangle between them as shown in Figure 6.

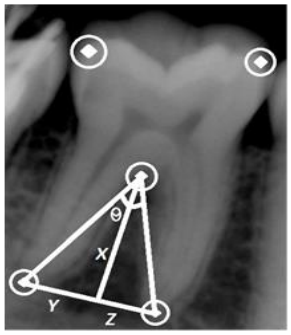

Fig 6 : Image showing root centre angle of tooth

Angle Ɵ denotes the root center angle for each tooth and it is calculated using the formulae given as

$$\theta = 180\text{-}\{tan^{-1}\left(\frac{x}{y}\right) + tan^{-1}\left(\frac{x}{z}\right)\} \qquad \text{Eq.(v)}$$

4. RESULTS AND ANALYSIS

4.1 Bite Mark Identification

The method of Bite mark identification was tested on a set of 15 overlays and bite mark images out of which 10 were positively identified. The identification algorithm was executed. The analysis for the set of single bite mark and overlay samples has been shown in Table 1 and Table 2.

Table 1. Bite mark analysis

Human Bite Mark (Sample 1)				
Upper jaw				
	Teeth1	**Teeth2**	**Teeth3**	**Teeth4**
Centroid	[415.03, 282.56]	[452.63, 234.39]	[503.63, 236.12]	[563.16, 263.13]
Major Axis Length	52.3	63.141	54.37	58.348
Orientation	70.322	54.865	-15.865	-20.17
Lower jaw				
	Teeth1	**Teeth2**	**Teeth3**	**Teeth4**
Centroid	[453.44, 400.01]	[494.68, 413.06]	[538.58, 404.47]	[578.2, 378.92]
Major Axis Length	41.548	43.506	46.045	40.945
Orientation	-14.74	-13.641	24.206	18.458

Table 2. Table showing overlay analysis

Table for Overlay				
Upper jaw				
	Teeth1	**Teeth2**	**Teeth3**	**Teeth4**
Centroid	[401.12, 345.85]	[446.69, 304.36]	[501.58, 309.57]	[556.61, 345.59]
Major Axis Length	53.698	64.349	70.938	54.911
Orientation	58.8	48.136	-23.5	-31.632
Lower jaw				
	Teeth1	**Teeth2**	**Teeth3**	**Teeth4**
Centroid	[397.93, 1123.9]	[442.07, 1140.5]	[486.04, 1131.5]	[525.83, 1107.2]
Major Axis Length	48.9	46.076	44.076	46.154
Orientation	-18.435	-17.733	21.593	19.656

Bite mark identification and Human Dental Radiograph Identification is based on the Orientation, Centroid, major axis length, root center angle and length to width ratio, however the numerical importance of the three is not equal and hence has to be scaled in order to obtain meaningful results.

Also the accuracy of positive identification depends upon the clarity of the images and intensity of bite marks. The method using image processing as described in section 3.2 takes less time i.e. around 2-3mins as compared to other methods discussed. The complexity in the comparison process is much lesser .Also the process is more accurate.

4.2 Dental Radiograph Identification

The algorithm discussed above in section 3.2.1 was implemented on six sets of AM and PM radiographs and the positive results were obtained. Table 2 shows the values obtained for comparison The software for simulation was built using MATLAB. This environment was chosen because it easily supports image processing, image manipulation and linear algebra. The software was tested against wide range of database.

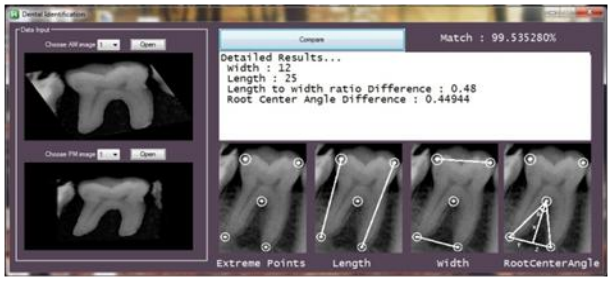

Fig 7 : GUI for radiograph identification

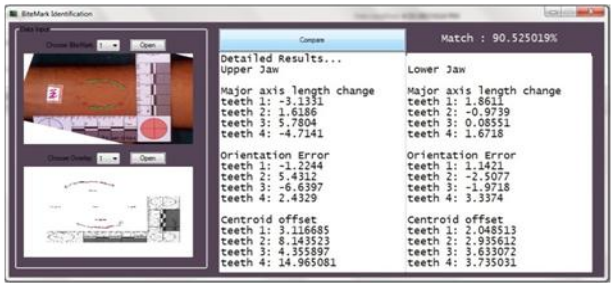

Fig 8 : GUI for Human Bite mark Identification

5. CONCLUSION

In case of Human bite mark identification, the algorithm discussed was implemented in MATLAB and the percentage of positive identification was found to be 67%. The method implemented was found to be much faster and efficient.

The time for execution to display results was 21.54 sec.

Authors also proposed a computer-aided framework for matching of dental radiographs based on length to width ratio and root centre angle. Experimental results on a small database indicated that this was a feasible approach. The errors can occur due to incorrect radiographic technique: the images being very blurred, or the region of interest was partially occluded so there was not enough information available to characterize the teeth.

The three PM images selected were positively identified and compared with the available database AM images. Time for execution to display results was found to be 19.36 sec.

Future work includes standardization and automatic selection of teeth edges for accurate marking of traces. Also the accuracy of positive identification depends upon the clarity of the images and the intensity of the bite marks. The method using image processing takes less time i.e. around 2-3mins as compared to other methods discussed. Also the complexity in the comparison process was much lesser with high accuracy.

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