Towards an Automated Dental Identification System (ADIS)

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Abstract

This paper addresses the problem of developing an automated system for postmortem identification using dental records. The Automated Dental Identification System (ADIS) can be used by law enforcement agencies to locate missing persons using databases of dental x-rays. Currently, this search and identification process is carried out manually, which makes it very time-consuming and unreliable. In this paper, we propose an architecture for ADIS, we define the functionality of its components, and we briefly describe some of the techniques used in realizing these components.

Introduction

Law enforcement agencies have been exploiting biometric identifiers for decades as key tools in forensic identification. With the evolution in information technology and the huge volume of cases that need to be investigated by forensic specialists, automation of forensic identification became inevitable. Forensic identification may take place prior to death and is referred to as *Antemortem* (AM) identification. Identification may as well be carried out after death and is called *Postmortem* (PM) identification. While *behavioral* characteristics (e.g. speech) are not suitable for PM identification, most of the *physiological* characteristics are not appropriate for PM identification as well, especially under severe circumstances encountered in mass disasters (e.g. airplane crashers) or when identification is being attempted more than a couple of weeks postmortem. Therefore, a postmortem biometric identifier has to survive such severe conditions and resist early decay that affects body tissues. Dental features are considered the best candidates for PM identification. This is due to their survivability and diversity. *Forensic odontology* is the branch of forensics concerned with identifying human individuals based on their dental features. Traditionally, *forensic odontologists* relied on the morphology of dental restorations (fillings, crowns, .. etc.) to identify victims. However, modern materials used in restorations and fillings have poor radiographic characteristics. Hence, it is becoming important to make identification decisions based on inherent dental features like root and crown morphologies, teeth size, rotations, spacing between teeth and sinus patterns.

Based on the information provided by experts from the Criminal Justice Information Services Division (CJIS) of the FBI, there are over 100,000 unsolved Missing Person cases in the National Crime Information Center at any given point in time, 60 percent of which have remained in the computer system for 90 days or longer, [12]. It is worth mentioning that the computing systems developed and maintained by CJIS are used by more than 94,000 agencies.

CJIS includes in its strategic plan the creation of an Automated Dental Identification System (ADIS), with similar goals and objectives to its Automated Fingerprint Identification System (AFIS) but using dental/teeth characteristics instead of fingerprints.

The ADIS will provide automated search and matching capabilities for digitized x-ray and photographic images. Cavities in today's children and their children will be virtually unknown due to the advances in dentistry [1], [2], [3]; e.g. pit and fissure sealants, and non-radiographic crowns. Currently, identification relies on visual analysis and comparison of dental images (radio graphs) based on dental work (fillings, crowns, etc.) rather than analysis and comparison of inherent tooth characteristics.

Background

There are several computer-aided PM identification systems. *CAPMI* [4] and *WinID* [5] are the most famous among these systems. However, these systems do not provide high level of automation, as feature extraction, coding, and image comparison are still carried-out manually. Moreover, the dental codes used in these systems only capture artificial dental work.

ADIS is a process automation tool, for postmortem identification, that is being designed to achieve accurate and timely identification results with minimum amount of human intervention. To this end, ADIS will not only automate some of the steps taken by forensic experts to examine missing and unidentified persons (MUP) cases, it will also be intelligently analyzing radiographs to utilize underlying image structures that are often difficult to be assessed merely by visual examination.

The Proposed System

Functionality

At a high level of abstraction, the functionality of the ADIS prototype can be described by one of two uses:
1) Identification of a subject, or
2) Maintaining the system

1. Identify Subject

The process of identifying a subject is initiated when a user submits the subjects' record (containing image and non-image information). The result of Identification should be a "*short*" list of candidates whose reference records are retrieved from the dental image Repository (DIR) and presented to the forensic expert who takes a final decision about the identity of the subject Missing or Unidentified Person (MUP).

2. Maintain the System

The process of maintaining the system primarily includes:

1- Updating the repositories (adding/purging) reference records.
2- Evaluating the performance of the system.
3- Updating the matching techniques (retraining, changing system parameters, changing component realizations).
4- Reporting problems, or substandard performance.

System scenarios

In this Demo, different components of the ADIS architecture (shown in figure 1) will be demonstrated.
In ADIS, we will use the dental codes that currently exist in the National Crime Information Center (NCIC) to enhance the retrieval and matching speed and performance, these codes are provided by CJIS. We note here that these NCIC codes are manually extracted from MUP. Although ADIS is designed to be an automated system, it will also allow the use of the NCIC database for results refinements. In order to populate the DIR, high-level features are extracted from all the reference images and are stored in the DIR.
When the user submits a subject record, that is typically an unidentified PM record, two processes occurs simultaneously

i) NCIC codes are extracted from the subject image (this step is not mandatory in ADIS, these codes can also be extracted automatically through ADIS techniques)
ii) High level features are extracted from the images, these features are extracted through the potential matching component as shown next

The NCIC extracted codes can help in narrowing down the search list from the order of hundreds of thousands to the order of hundreds, however this is an optional step. High-level features are used to retrieve a list potential match from the DIR. This process happens through the potential search component presented next. This list of potential matches (candidate images) will be in order of 100-150 records.
The potential search matching component is based on feature extraction and archival retrieval techniques, in which a set of features are extracted from the images, encoded as a feature template, then used as a query for searching the dental feature database for the records with the most similar features, [6]. The dental features database will be created from the dental image database by extracting dental features from the dental images, coding them into feature templates, then storing them onto the dental features database.
Once the list of candidate images are created, they are fed to the image comparison matching stage. This stage processes the query image through enhancement and segmentation stages. Then this processed query image is matched against the list of candidate images that are provided from the potential matching component. This comparison matching stage aims at reducing the list of candidate images from the order of hundreds to the order of 30-35 images to be delivered to the forensic expert for a final identification decision. Once a positive identification is made, for a subject image, then its corresponding reference image if removed from the DIR. If a positive identification can't be made for a subject image, then this image is added to the DIR as a new missing or unidentified image. In our system, typically if the subject record is AM, then the reference records are PM and vice versa. However we will also allow both subject and reference images to be AM, this is to avoid database redundancy if a AM record of a missing person was submitted multiple times.

The Proposed Architecture of the System

In this section we will briefly describe the main three components in ADIS, the DIR, the Potential Search Matching component and the image comparison component, as in figure 1.

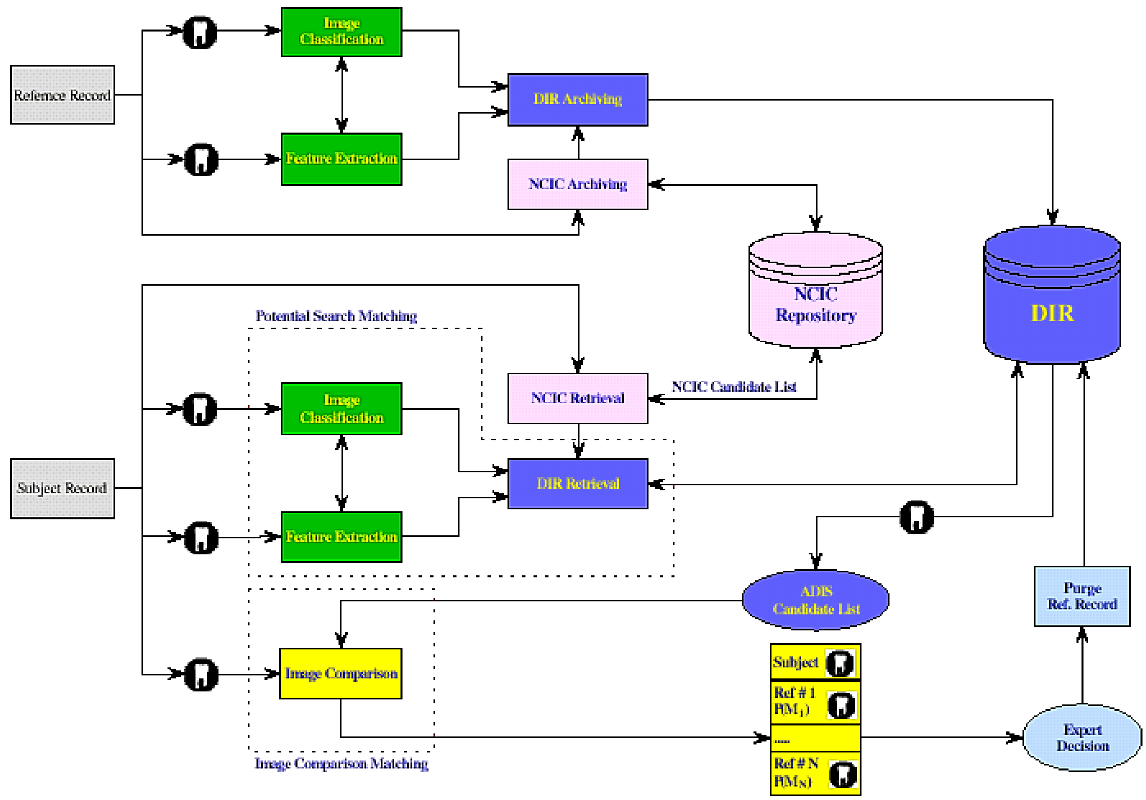

Fig 1 Block Diagram of ADIS

The upper parts of the architecture is used to archive the DIR with reference records. The lower part of the architecture is used for identifying a subject record. This lower part consists of the potential search matching component that retrieves a candidate list from the DIR and an image comparison that identifies the short match list to the forensic expert.

The DIR

The Digital Image Repository (DIR) is a central system, which allows the voluntary submission, storage, and retrieval of digital images relating to missing and unidentified person investigations.

The DIR will serve as an electronic centralized location where law enforcement agencies can submit digital images of dental x-rays, and other information regarding missing and unidentified person cases. It will eliminate the need to obtain x-rays from other law enforcement agencies for identification purposes. In addition it will help the forensic scientist to access the DIR in order to study the available images for quickly determining exact match. The repository will contain image information as well as non-image information for each missing/unidentified person. The procedure of DIR archiving is carried out after extracting dental features from each case's dental images. Here we list some of the high level features that will be extracted from each tooth

1. The shape and size (width, length) of each tooth. 2. The root features: number, curvature, and length of each one.
3. Existing/Extracted tooth. 4. Teeth spacing, the spacing between two adjacent teeth.

As all of these features are relative to the image size, they must be normalized. In addition to the dental features the DIR will contain information about each image and non-image information about each case.

1- Case ID, a unique number given to each case. 2- AM/PM, if this record is for a *Postmortem* or *Antemortem*
2. Date last update, the last time this record was updated.
3. For each image.
   a) Image type, there are 6 types of image classified according to the view they are taken from and their coverage.
      a) Date image was taken.

b) Dental features associated with each tooth in the image.

4. Total # of teeth, which depends on having the all series for whole teeth.

We can use the DIR system for archiving and retrieval as follows:

(I) DIR archiving

1. Reference record archiving request (Non-image information & images).
2. Archive the non-image information.
3. For each of the submitted image.
   - Archive image information.
   - Extract features for each tooth.
4. Calculate the total number of teeth while archiving the whole available images.

(II) DIR Retrieval

1. Submit a subject Image(s).
2. Extract features.
3. Search the DIR for highly matched records according to some similarity measures, these measures have to be defined according to the importance of the features extracted.
4. List the final matched records' information.

<u>Potential Search Matching component</u>

This component extracts the high-level dental features and stores it in the DIR, then it retrieves a list of candidate images for every subject image. As noted before, this list is in the order of 100-150 records. In extracting the high level features, there are two methodologies adopted in ADIS, the first one focuses more on extracting the contour of roots and crowns, that are usually important in periapical images, fig 4, [4]. The second methodology focuses on extracting the contour of each individual tooth in bite-wing images, fig 3, [4]. In this section we will briefly describe each methodology.

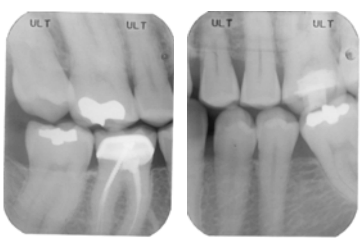

Fig. 3 Bitewing dental images

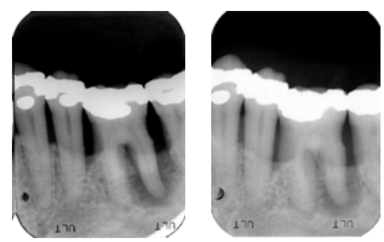

Fig. 4 Perapical dental images

Root and Contour Extraction for periapical images

This methodology involves three stages radiograph segmentation, Contour Extraction and Shape matching as described in detail in [7]. The radiograph segmentation stage utilizes the integral projection [9] histogram in horizontal directions to find the gap between the mandibular and maxillary teeth (Fig. 5) and the intergral projection histogram in vertical directions to find the gap between neighboring teeth (Fig. 6).

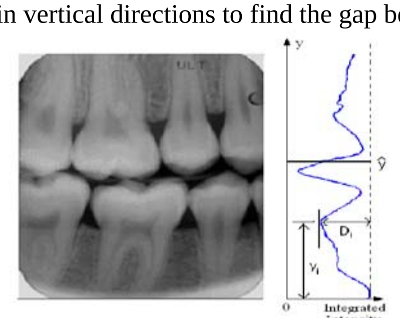

Fig. 5 Integral projection on the y axis.

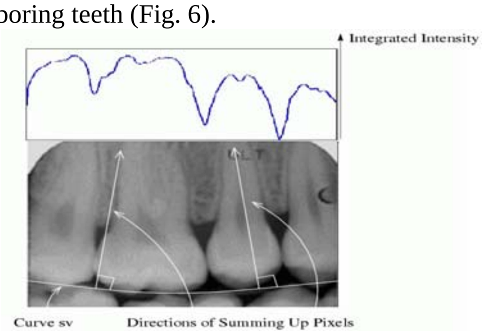

Fig. 6 Integral projection of pixels of the upper teeth along the lines perpendicular to the curve of the valley.

The contour extraction stage has two sub-stages: crown shape extraction and root shape extraction. While detecting the crown contour, by assuming that the intensities of background pixels form the first mode in the intensity histogram, for a pixel with intensity, we can find the probability for it to be a tooth pixel, and the probability for it to be a background pixel. Then in each radial line through the center of the crown area, we find the most possible boundary point. The probability for a point P to be a boundary point is defined as:

$$p_B(P) = p(\omega_b \mid I_{outer})\, p(\omega_t \mid I_{inner}),$$

where I_{outer} and I_{inner} are the neighboring points of P, P_{outer} and P_{inner} ,as shown in Fig. 7.

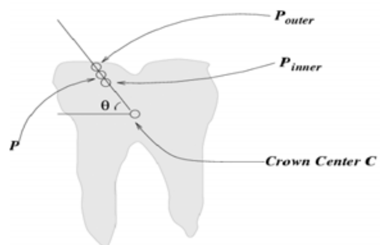

Fig. 7 Detection of crown shape.

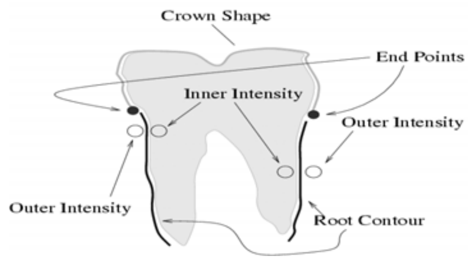

Fig. 8 Root shape detection.

The root shape detection is based on the two ends of the detected crown contour (Fig. 8). For the teeth in the lower jaws, if the *i*th point on the left/right root contour has coordinates (x_i, y_i), the $i+1$th point, (x_i+1, y_i+1), is computed iteratively as:

$$x_{i+1} = \arg \max_{x_i - r \le x \le x_i + r} (I_{inner} - I_{outer}),$$

$$y_{i+1} = y_i + h,$$

where r is radius of the search space and h is the increment in the vertical position for each new point. The iteration ends when y_i increases beyond the image boundary, or $\max_{x_i - r \le x \le x_i + r} (I_{inner} - I_{outer})$ is less than a threshold.

In the Shape Matching stage, the shapes extracted from the query image must be matched to the shapes extracted from the database images. One of the main difficulties in matching AM and PM images is due to the fact that they were taken at different times often as long as several years. Thus the viewpoints are usually slightly different, which causes an *affine transformation* between the two images that must be considered prior to shape fitting. We confine ourselves with a subclass of the affine transformation. In particular, we do not consider the shear transformation, because the shear is negligible in AM and PM images. More details about shape matching can be found in [7]

Contour Extraction for Bitewing images

In this methodology, Bitewing radiograph images are automatically enhanced and segmented. This methodology involves two main stages, Bitewing enhancement and bitewing segmentation.

In the bitewing enhancement stage, dental radiographs contain three distinctive regions: background, teeth, and bones. Usually the teeth regions have the highest intensity, the bone regions have high intensity that sometimes is close to that of the teeth, and the background has a distinctively low intensity. It is easy to separate the background by threshold-based methods, but these methods usually fail to discriminate teeth from bones, especially in cases of uneven exposure. To overcome this problem, the first step we use is to enhance the image's contrast. Top-hat and bottom-hat filters can be used to extract light objects (or, conversely, dark ones) on a dark (or light) but slowly changing background [8]. We use both the top-hat and the bottom-hat filters on the original image, and combine the results by adding to the original image the result of the top-hat filter, and subtracting the result of the bottom-hat filter, so that the teeth areas can be enhanced and the bone and background areas can be suppressed as well. Fig. 9b shows a result of the enhancement algorithm.

In teeth segmentation, we use window-based adaptive threshold to segment the teeth. The idea is to examine the intensity values of the local neighbors of each pixel. If the intensity value of the pixel is larger than the average intensity values of its neighbors, then it is classified as a tooth pixel, otherwise it is classified as background. To separate each tooth region, we apply a binary morphological operation to eliminate small noisy parts and smooth the teeth regions. Then, we subtract the teeth areas from the original image to obtain the bones and the background regions, and apply simple thresholding to separate the bones from the background. The results are shown in Fig. 9b and 9c.

(a) (b) (c) (d) (e)

Fig. 9. Teeth segmentation. (a) Original image; (b) Result of top-hat enhancement. (c) Morphological operation (d) Separated roots and crowns. (e) Final segmentation result.

The positions of the bones provide information to approximate the gum line and separate the crown and root parts of the teeth. As shown in Fig. 9d, the line that connects the tips of the bones approximates the gum line. To determine the gum lines we need to separate the bones of the upper and the lower jaws and identify the tips of the bones. From the detected bones images, the upper and lower jaws are separated using integral projection [9]. More details about this stage can be found in [11], Fig. 9e shows the final result of the segment stage.

Image Comparison Matching component

In this component the radiograph images is processed through four main stages, enhancement, segmentation, alignment and matching. While the enhancement stage removes noise and enhances the quality of the radiograph images, the segmentation stage automatically segments the dental image into rectangular regions, where each region contains each tooth with its surroundings. The alignment stage registers/aligns different regions independent of their orientation, scale and translation. Theses regions are then matched through a neural network based matcher as shown next. We here give a brief description of all stages except the alignment stages that is still evolving.

Enhancement

Enhancement of a dental radiograph is the process of producing an improved quality image out of a degraded quality input image of a dental radiograph. In periapical and bite-wing views, we identify three main classes of "objects"; teeth, gum, and air. A tooth maps to an area with mostly "bright" gray scales (except for the pulp tissue) while the gum maps to areas with "mid-range" gray scales, and air maps to "dark" gray scales.

Fig. 11 shows an example of enhancing a periapical dental radiograph using our ADIC enhancment scheme. The original radiograph is shown in (a), the result after applying the enhancement transform is shown in (b), Note that teeth edges are emphasized. The gray scale histograms before enhancement and after enhancement are shown in (c) and (d) respectively. The solid vertical lines lines in (c) represent the computed marker gray scales and the dottet line represents a threshold gray scale used for adaptive enhancement.

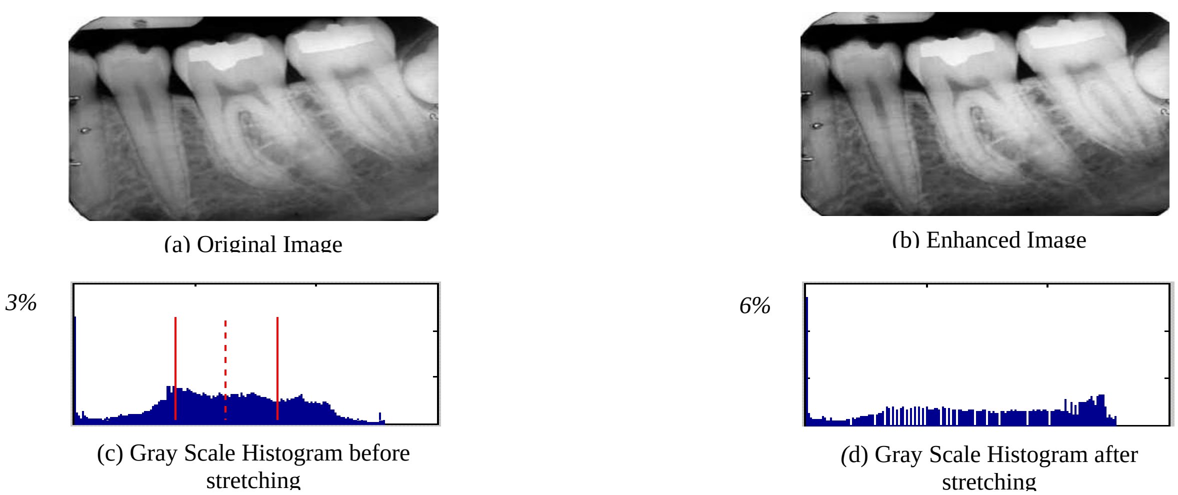

Fig 11 ADIS image enhancement using gray scale contrast stretching

Segmentation

In this stage, we only consider segmenting radiograph images into regions, where each region contains each individual tooth in it, rather than extracting the exact contour as in previous sections. This is due to the nature of the matcher that deals with regions and matches them with no need for the exact root or crown contour. We utilized the morphological filtering approach in this segmentation stages as described in [8]. Fig. 12 shows samples of our results with region based morphological filtering segmentation.

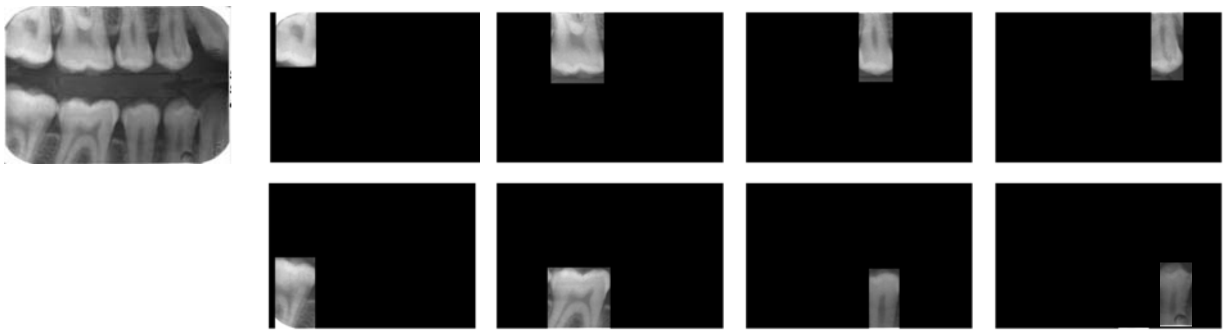

Fig. 12 Morphological Filtering Segmentation

Matcher

In this stage, we consider the decision-making stage of the prototype ADIS. The input to the decision-making stage is a pair of preprocessed representative segments from a candidate and a reference radiographs. The decision-making stage extracts embedded features from the input pair, and then determines their matching probability based on the measured differences between extracted features. As we previously mentioned, this stage is composed of two layers: the feature extraction and the decision. More details about the matching stages can be found in [10].

Conclusions and Future work

In this paper, we presented a prototype for an automated dental identification system (ADIS). ADIS will be used by law enforcement agencies for resolving cases of missing and unidentified persons. We proposed an architecture for ADIS and briefly described its components and their functionalities. Our future work will address several important problems such as the migration from region-based image matching to case-based image matching, processing poor quality radiographs, and retrieval from the DIR.

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