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Original Research Article

Automatic frontal sinus recognition in computed tomography images for person identification

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ABSTRACT

In many cases of person identification the use of biometric features obtained from the hard tissues of the human body, such as teeth and bones, may be the only option. This paper presents a new method of person identification based on frontal sinus features, extracted from computed tomography (CT) images of the skull. In this method, the frontal sinus is automatically segmented in the CT image using an algorithm developed in this work. Next, shape features are extracted from both hemispheres of the segmented frontal sinus by using BAS (Beam Angle Statistics) method. Finally, L_2 distance is used in order to recognize the frontal sinus and identify the person. The novel frontal sinus recognition method obtained 77.25% of identification accuracy when applied on a dataset composed of 310 CT images obtained from 31 people, and the automatic frontal sinus segmentation in CT images obtained a mean Cohen Kappa coefficient equal to 0.8852 when compared to the ground truth (manual segmentation).

1. Introduction

Biometric identification refers to the use of physical or behavioral characteristic to determine the person identity. In order to be used for person biometric identification a physical or behavioral characteristic must have some properties such as: universality, uniqueness, permanence, and acceptability [1].

Fingerprints and faces characteristics are frequently used for person biometric identification in commercial, banking, and government applications [1]. However, for the identification of deceased people, in forensic applications, these characteristics are not always available, because they derive from soft tissues of the human body that decomposes soon after death. In these cases, DNA features could be an alternative. However, in carbonized bodies, for instance, the characteristics of DNA cannot always be recovered [2]. Besides, DNA analysis is very expensive for applying to every case and it is not reliable in some cases as dry bones [3]. Therefore, in many human identification situations, the use of biometric features extracted from the bones, the hardest tissues of the human body, such as the frontal sinus features, may be the only option.

Frontal sinus consists of a paired irregularly shaped loculated cavity, located in the frontal bone [4]. The uniqueness property of the frontal sinus was first observed by Zuckerkandl, in 1875, when he called attention to its asymmetric morphology [5]. In 1927, Culbert and Law described the first human identification through morphological analysis of frontal sinus that was accepted in a United States court of law [6]. In 1943, Schuller was the first to suggest the possibility of identifying a deceased person by comparing frontal sinus radiography images [7]. In the beginning of 21st century, Ribeiro [8] and Kirk, Wood and Goldstein [9] reported positive results in skeletal identification using frontal sinus information extracted from radiography (X-ray) images.

The frontal sinus asymmetry, among other particular characteristics, has motivated several studies in the last few decades aiming people identification through the analysis of frontal sinus measurements obtained from X-ray films. Many of these studies have established that the highly variable radiographic pattern of the frontal sinus is unique to every individual, even among monozygotic twins [7–10].

The frontal sinus is increasingly being used for postmortem human identification. In 2007, Tatlisumak et al. [3] defined a system for the identification of unknown bodies by using computed tomography images of frontal sinus. This system, called FSS, included simple features as F (presence or absence of frontal sinus), S (intersinus and intrasinus septum) and S (scalloping). Measurements selected for this study were width, height, anteroposterior length, total width of two sinuses, the distance between the highest points of the two sinuses and the distance of each sinus to its maximum lateral limit. All the features and measurements were coded according to the FSS system defined for

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each case and coded formulas were compared. At least 93% of the formulas could be eliminated for a case by using FSS system.

In 2015, Soares et al. [11] performed a study to evaluate the applicability of human identification parameters, established by Tatlisumak et al. [3], using cone-beam computed tomography tridimensional reconstruction and extraoral radiographs of the frontal sinus. They concluded that, despite some advantages of using X-ray, such as the low costs, comparison of radiographic images has limitations because it is a subjective test that depends on the expert's experience and the radiographic image can vary significantly according to the incidence of the X-ray beam. They recommend the use of CT imaging examination for proper study of the paranasal sinuses, since it enables the acquisition of sectional images, three-dimensional scans of the sinuses, and eliminates the structural overlapping observed in X-ray images.

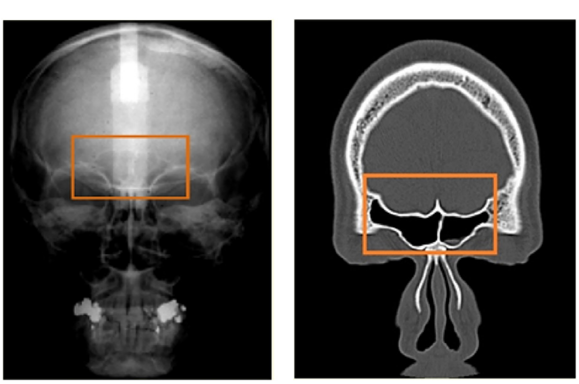
In 2015, Hashim et al. [12] made a study that tested the practical relevance of prescribing superimposition by superimposing ante-and-post-mortem frontal sinus patterns recorded in real case situations and ante-and-post-mortem of frontal sinus patterns in simulated cases, recorded using archived skulls, resulting in a perfect match of radiographs from the same skull only when the orientation of the skull obtained for the first (simulated ante-mortem) recording is unaltered for the second (simulated post-mortem) recording. According to the authors, for the real life cases, normally the superimposition is not possible.

In 2016, Rabelo et al. [13] studied the applicability of the FSS system proposed by [3] in order to identify persons, by means of the frontal sinus measures acquired from frontal and lateral cephalometric radiographs. They reported good results.

Researches also have been carried out in order to identify gender by analyzing measurements of the frontal sinuses obtained from X-ray films. Belaldavar et al. [14], for instance, concluded that the area, height and width of the frontal sinuses are, in average, bigger in men than in women. Uthman et al. [15] and Carvalho et al. [16], conducted experiments focusing gender discrimination and human identification using CT images and structures of the paranasal sinuses (frontal sinuses and other cranial structures).

In general, these previous works are based on manual or semi-automatic frontal sinus segmentation methods. The review by Xavier, Terada and Silva [17] showed that there were no fully automatic frontal sinus segmentation method proposed in literature so far.

Another characteristic of previous works is that they are based on X-ray images. However, computed tomography (CT) images allow better frontal sinuses segmentation and recognition than X-ray images because of the better contrast provided by the CT technology. Fig. 1 shows an X-ray image and a computed tomography (CT) image of two distinct individuals, with the frontal sinuses enclosed by rectangles. One can observe that the CT image (right) allows an easier and better analysis of the frontal sinus structures, when compared to the X-ray image (left). Besides, CT scans produce sequences of images, allowing 3D analysis of the frontal sinus structures.



(a) (b)

Fig. 1. Frontal sinuses enclosed by rectangles: (a) X-ray image and (b) computed tomography image.

The goal of our work is to propose and develop a fully automatic and robust method for frontal sinus segmentation and recognition using computed tomography images to be used for person identification.

2. Frontal sinus

Frontal sinus consists of a paired irregularly shaped loculated cavity, located in the frontal bone, which communicate with the nasal fossa via the infundibulum [4]. This cavity develops embryonically from an ethmoidal cell and is not visible at birth. It starts developing during the second year of life, reaching its maximum size at the age of 20.

As the frontal sinus remains stable even after death [4,10] it is very suitable for post mortem person identification. The configuration of the frontal sinus is claimed to be unique for each individual [4,7,9,10] and is controlled by genetic and environmental factors. Frontal sinus variations have been reported in the literature even for monozygotic twins [4,10].

Fig. 2 shows three CT images of three different individuals. As one can observe in the red rectangles, the three frontal sinuses have very distinct and particular characteristics that can be used to identify the individuals.

3. Proposed method

The new method proposed in this work for person identification based on frontal sinus features extracted from computed tomography images has three main stages:

- Frontal sinus segmentation;
- Frontal sinus feature extraction; and
- Frontal sinus recognition.

3.1. Frontal sinus segmentation

The frontal sinus segmentation stage consists in automatically detecting in CT images the pixels belonging to the internal region of the frontal sinus.

The first step of this process is the binarization of the gray level CT image, which is carried out by replacing the original gray scale pixel values by 0 or 1, according to a threshold value. This technique was chosen because it is fast and results in very good quality segmentation since CT images present high contrast in the frontal sinus region, as one can observe in Fig. 2 (black regions completely surrounded by white borders).

In our method, the threshold value used for binarization is automatically defined. Given I, an $m \times n$ CT image, its gray level histogram H is calculated. Then, by considering the rightmost mode (m_r) of H, cranial bones regions in the CT images can be easily detected since they are associated with the brighter regions of I. So, the threshold value (t) of the binarization stage is taken as 80% of m_r.

Fig. 3(b) shows the logarithm of the gray level histogram H of the CT image of Fig. 3(a), with the threshold t represented by the vertical red line located at the left side of the rightmost mode of H. Fig. 3(c) shows the binary image B_1 obtained automatically with the binarization process applied to the gray level CT images I presented in Fig. 3(a).

After this first binarization, the next step is to find the region of interest (ROI) of the CT image, that is, the smaller rectangle that contains the frontal sinus. An initial ROI, called R_1, is taken as the