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System of gender identification and age estimation from radiography: a review

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ABSTRACT

Under extreme conditions postmortem, dental radiography examinations can play an essential role in individual identification. In forensic odontology, individual identification traditionally compares antemortem dental records radiographs with those obtained on postmortem examination. As such, these traditional methods are vulnerable to oversights or mistakes in the individual identification of unidentified bodies. Digital technology can develop forensic odontology well. An automatic individual identification system is needed to support the forensic odontology process more easily and quickly because there are still opportunities to be created. We aimed to review the complete range of recent developments in identifying individuals from panoramic radiographs. We study methods in gender identification, age estimation, radiographic segmentation, performance analysis, and promising future directions.

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1. INTRODUCTION

Individual identification involves investigating criminal cases, natural disasters and forensic science. Identification or determination of individu can be done by comparing antemortem and postmortem data [1]. Individual identification can be done using several elements of the human skeleton, namely the pelvis, skull, teeth, and soft tissues [2]. Victims are identified through primary and secondary identification. Secondary identification includes identification of gender, age, and race [3], [4].

Whereas primary identification tools are based on fingerprint, dental and deoxyribonucleic acid (DNA) analysis, secondary identification includes individual descriptions (tattoos, scars and gender); medical findings; clothes and evidence inside the victim's body. Primary identification in forensic dentistry is the application of all relevant dental disciplines in investigations to obtain postmortem data, assisting in determining the authenticity and identity of victims and perpetrators for the sake of law in the judicial process and upholding the truth. Teeth in the oral cavity are the most challenging parts of the body, have their characteristics, and are resistant to temperature, chemicals and trauma, so they are very suitable for identification. Gender identification in forensic anthropology and dentistry can be carried out using various methods, including morphological or non-metric, metric, geometric, and molecular morphometric methods [5]. This forensic odontology method is highly accurate and almost identical to fingerprint identification. In Indonesia, it is still difficult to obtain antemortem dental data because not all individuals have archived dental

data. Only a few professions have written information about teeth, such as the military and workers in the aviation world. If antemortem data are unavailable, identification with dental tools may not reach the individual level.

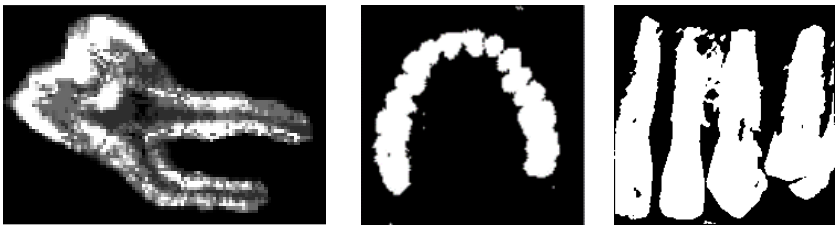
In addition to examination with dental, the bone examination can also estimate the age if the victim to be identified does not have any remaining teeth available [6], [7]. In certain conditions where teeth cannot be used as an identification tool because the data on the victim's teeth is incomplete or in victims with edentulous conditions that do not allow identification using teeth, an alternative method using bones is needed to assist the identification process at the victim. The accuracy rate for determining gender when using the pelvis is 95% and when using the skull (cranium) is 90%. The parts of the skull that can use to identify are the supraorbital ridge, mastoid process, palate, orbit, and mandible. The mandible is the strongest and largest bone in the face. Several studies state that mandibular assessment is more significant for differentiating gender and providing age estimation information. Gender identification and age estimation can be done using radiography [8]. The recommended radiographic technique is radiography that provides an image of the jaw both frontally and laterally, for example, lateral cephalometric radiography, posteroanterior cephalometric radiography, panoramic radiography and cone-beam computed tomography (CBCT).

In addition to gender identification, age estimation plays an important role in every aspect of life. Age information is always needed in various matters such as education, employment and health. Age estimation can be done on living or dead individuals. Age estimates can be used on living individuals to clarify criminal and civil matters. Meanwhile, for individuals who died, age estimation is part of the identification of the deceased, for example, due to an accident. Gender identification and age estimation methods can be done automatically. Automated processes can make a significant social contribution in individual identification. We studied methods in gender identification, age estimation, radiographic segmentation, performance analysis.

The paper is organized as: section 2 briefly reviews the relevant literature segmentation of panoramic radiography. Section 3 provides a description of age estimation from panoramic radiography. Section 4 describes gender estimation-based panoramic radiography. The baseline results and performance comparison are presented in section 5. Finally, section 6 summarizes this work's contributions and conclusion.

2. RADIOGRAPHY SEGMENTATION

The segmentation process is a step to separate objects from the background. Many segmentation studies have been carried out previously. We present several studies of the results of tooth segmentation in Figures 1(a) to 1(c) and the results of mandibular segmentation in Figure 2. Figure 1 is the result of tooth segmentation, and the difference is the method. gaussian kernel fuzzy c-means clustering method on CBCT images Figure 1(a), deep learning (DL) method on CBCT images Figure 1(b), and decimation-free directional filter bank thresholding and multistage adaptive thresholding methods on panoramic radiography Figure 1(c).



(a) (b) (c)

Figure 1. The tooth segmentation of panoramic radiography methods: (a) Gaussian kernel fuzzy C-means clustering (GK-csFCM) [15], (b) DL [16] of CBCT, and (c) decimation-free directional filter bank thresholding (DDFBT) and multistage adaptive thresholding [17] of panoramic radiography

Figure 2 results of mandibular segmentation on CT scan images Figures 2(a) to (d), CBCT Figures 2(e) to (g), and panoramic radiographs Figure 2(h) and Figure 2(i). Method uses the symmetric convolutional neural network (SCNN) method Figure 2(a), recurrent convolutional neural networks (RCNN) for mandible segmentation (RCNNSeg) Figure 2(b), fuzzy connectivity Figure 2(c), U-Net convolutional neural network (CNN) Figure 2(d), conditional statistical shape model (SSM) Figure 2(e), Super-voxels and graph clustering Figure 2(f), Recurrent SegUnet Figure 2(g), shape-aware segmentation for mandible segmentation (SASeg) Figure 2(h), active contour Figure 2(i). The segmentation process is very influential in recognizing objects in the image. If the segmentation results fail, then the thing is easier to identify. The following are some studies related to tooth segmentation on radiographs: Segmenting teeth on panoramic radiographs using quantum particle swarm

optimization (QPSO) [9]. Research segmentation is segmenting the maxillary and mandibular margins on panoramic radiographs [10] and evaluating the results of tooth segmentation on panoramic radiographs using the CNN method [11] and evaluating CNN methods for detecting parts of panoramic radiographs ResNet-101, Densenet161, Vgg19_bn, and AlexNet [12]. Evaluating the results of the DL method in detecting or automatically segmenting teeth, fillings, roots, and dental implants on panoramic radiographs [13]. Segmenting or identifying and classifying the type of Maxillary canine impaction on panoramic radiography with the DL method [14].

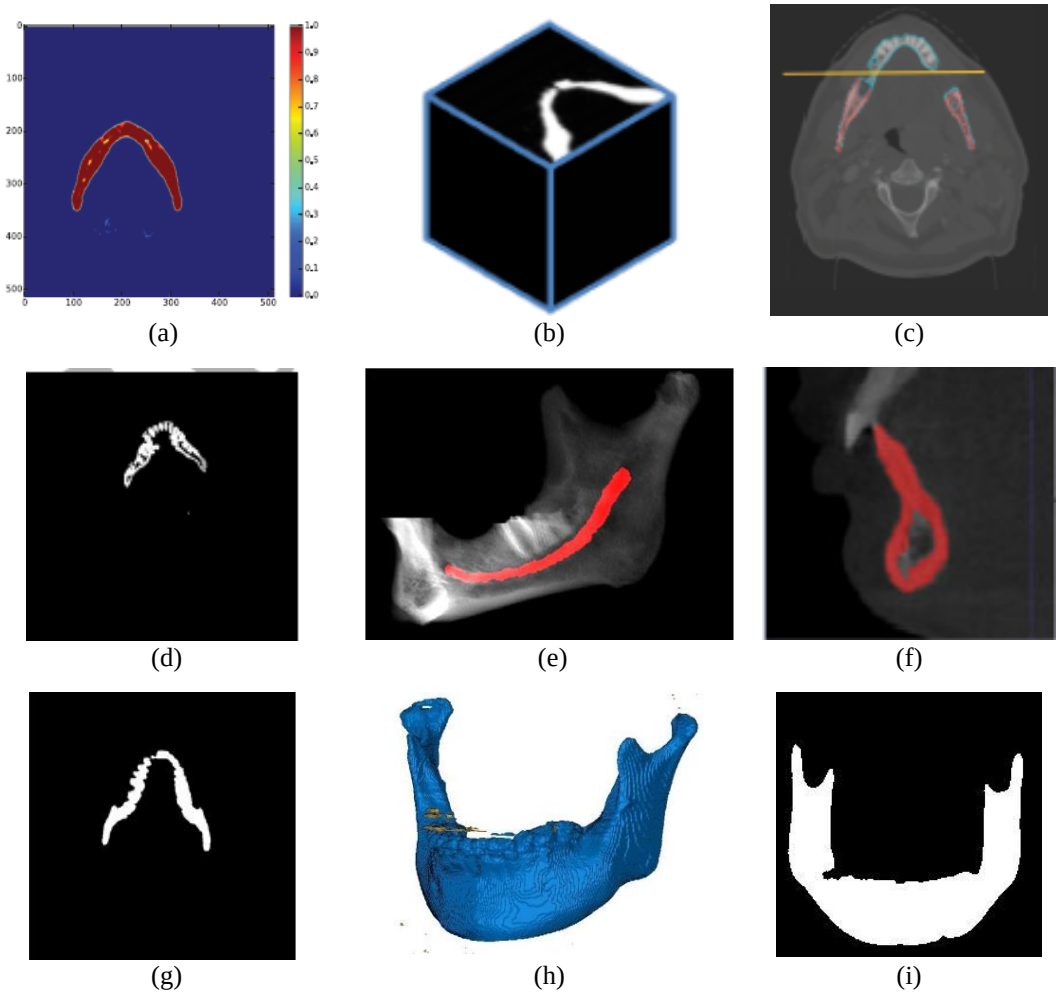


Figure 2. The mandibular segmentation methods: (a) SCNN-11C [18], (b) RCNNSeg [19], (c) fuzzy connectivity [20], (d) U-Net CNN [21] of CT scan, (e) SSM [22], (f) super-voxels and graph clustering [23], (g) recurrent SegUnet [24], (h) SASeg [25] of CBCT, and (i) active contour [26], [27] of panoramic radiography

3. AGE ESTIMATION FROM RADIOGRAPHY

Research has been done on estimating tooth age on radiographs, including analyzing the Willems method for estimating the tooth age of children on panoramic radiographs [28]. Marinkovi *et al.* [29] estimating adult tooth maturity using the Willems method on panoramic radiographs, estimating age at the time of identification using premolars using Cameriere's method [30] and estimating age based on changes in tooth pulp size using the Kvaal method [31]. Kelmendi *et al.* [32] evaluating the accuracy of tooth age estimation using a method by Demirjian, Chaillet, and Willems and evaluating tooth age estimation of the three methods Demirjian, Willems, and Blenkin and Evans [33] and evaluating how to identify the age and maturity of the tooth on panoramic radiographs using Willems and Cameriere's method [34]; evaluating the tooth age using the Chaillet and Dermijian's method on panoramic radiographs using the multilayer perceptron method [35]; evaluating the morphometric assessment of tooth chronology or estimating the tooth age using the DL method [36]; evaluating the measurement of age estimation using the Demirjian and Willems method on panoramic radiographs [37]. Several previous studies have conducted age estimation using

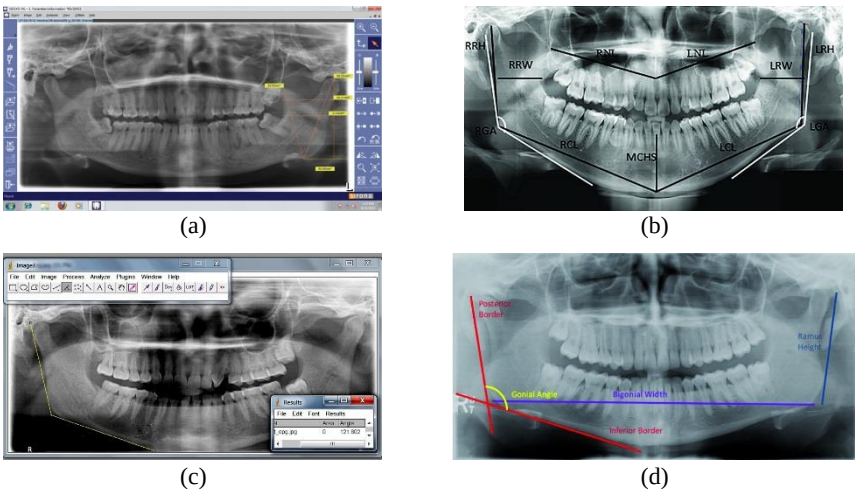
mandibular radiographic parameters, with the following parameters: length of the ramus (mm), the height of the body of the mandible (mm), the distance of the lower border of the mandible (LB) to the inferior margin of mental foramen (IMF) (mm) (left and right), a distance of inferior margin of mental foramen (IMF) to the crest of alveolar bone (CAR) (mm) (left and right), gonial angle, antegonial (AG) angle, antegonial (AG) depth, the width of the cortex at the body and the antegonial region (TCB at AG) [38], gonial angle, length of ramus, bigonial width, bicondylar breadth [39], ramus height, bigonial width, gonial [40]–[42], Gonial angle, Ramus length, Condylar length, Ramal notch depth, Cortical bone thickness [43].

Several previous studies carried out the process of age estimation based on panoramic radiographs using teeth and mandibles with the method used for matching dental data with machine learning (ML), neural networks (NNs), DL, and CNN. The age estimation using teeth on panoramic radiographs is made automatically. However, the mandible identification process on panoramic radiographs is done manually or semi-automatically. Manually by measuring several mandibular parameters with standard measuring instruments. Semi-automatic by measuring mandibular parameters with applications such as ImageJ, Master View, Sidex software, and RadiAnt Dicom Viewer. Figures 3(a) [39] and 3(b) [44] show the manual way. The measurement process uses standard measuring instruments. Figure 4 is an example of the process of measuring with the application. Some of the applications used for measurement are SIDEXIS-XG [45] Figure 4(a), IG measure software [46] Figure 4(b), and ImageJ tool [42] Figures 4(c) and 4(d).

(a)

(b)

Figure 3. Manual measuring process: (a) gonial angle, length of ramus, bigonial width, bicondylar breadth [39] and (b) gonial angle, height of the ramus, bimental breadth, and bigonial width (A) bicondylar breadth (B) [44]



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

Figure 4. Measuring process using (a) SIDEXIS-XG software [45], (b) IG measure software [46], (c) and (d) ImageJ tool [42]

4. GENDER IDENTIFICATION FROM RADIOGRAPHY

Identity can be determined by using two identification methods, namely primary and secondary identification. Primary identification includes fingerprint, DNA, and dental examination. Secondary identification includes a visual examination, photography, property, medical, lip print examination, age, race, and gender. The primary identification commonly used in forensic teams is a tooth. However, when teeth are unavailable, bone can be an alternative. The most dimorphic bone for identification is the mandible. The mandibular bone can be used to identify the gender and age of the victim. Identification of victims with incomplete or damaged bodies will be difficult to identify. Primary identification with teeth or bones as an alternative to identify victims in damaged or incomplete cases. Identification using teeth and bones has the advantage of being fire resistant. The identification process uses teeth by comparing antemortem and postmortem data. If the teeth are incomplete, bone alternatives are also appropriate for victim identification. Previous studies used the mandibular bone identification process by measuring the mandibular parameters. Some studies carried out measurements manually with measuring instruments or semi-automatically. Examples of parameters measured are ramus height, gonial angle, ramus length, body height, bigonial width, bicondylar breadth, coronoid height, mandibular corpus length, and anterior mandibular corpus height.

The following research conducted gender identification: Looking for the relationship between changes in the mental foramen's size and the mandibular ramus's height with gender and age [47], evaluating the relationship between chronological age and gender based on mandibular condyle on CBCT [48]. Also evaluating the effect of gender and age on ramus height, gonial angle, and bigonial width on panoramic radiographs [49]. Perform gender identification based on the mandible, mental, and gonial angles [50]. Okkesim and Erhamza [51] evaluating mandibular morphometric measurements on CBCT for gender identification. Performing morphometric evaluation of maxillary sinus CBCT to determine gender dimorphism [52]. Lee *et al.* [53] analyzing changes in the anatomy of the teeth and mandibular structure on panoramic radiographs, evaluating gonial angle measurements on both cephalometric and panoramic radiographs for identification of gender and age [54], comparing the diagnostic accuracy of mandibular and maxillary structural development with age and gender changes [55], checking dental accuracy on panoramic radiographs to identify humans [1]. Determining gender and age based on teeth by applying NN computing [56], [57]. Performing forensic identification on a disaster victim by matching the teeth using panoramic radiography based on contour feature extraction [58], [59]. Performing forensic identification of mass victims' teeth on panoramic radiographs using the CNN method [60], evaluating and verifying the accuracy of gender identification based on teeth on panoramic radiographs using the ML method [61]. Ortiz *et al.* [62] matching teeth on panoramic radiographs with ML to identify a individu, using the NN method, identifying unknown bodies based on tooth contours on panoramic radiographs [63].

Based on several review articles related to artificial intelligence [64], [65] vision computing technology, or related to dental forensic identification [66], [67], that: Identifying the victim alive or dead based on the characteristics of the individu aims to ascertain their identity. Identification of a victim can be both biological and non-biological identities. Non-biological identity includes identity cards, driving licenses, and clothes. Biological identity can be known through the body's anatomical structure, bones, teeth, blood, fingerprints, hair, profiles, DNA, and identity on the lips.

5. RESULT COMPARISON

Most of the gender identification and age estimation is based on teeth automatically. However, some studies related to dental identification are in Table 1. Figure 5 is a proposal from Fan *et al.* [60] research using teeth radiography in identification. Identification from panoramic dental radiographs (PDR) uses a CNN (DENT-Net). The DENT-Net took 128×128×7 image size as input, including the details of the feature extraction from the PDR. Figure 6 is an example of the identification process based on teeth using the CNN method. Identify individuals with dental panoramic. Panoramic dental images were carried out by morphology and contour feature extraction so that they could be classified using the CNN method [63].

Table 1. Identification performance

Method	Evaluation
Multi-layer perceptron neural network [56], [57]	Age error difference ±8.9, accuracy gender 98%
Convolutional neural network [60]	Accuracy 85.16%-97.74%
Machine learning [61]	Precision methods KNN, neural network, naive Bayes (NB), Logistic regression (0.86, 0.84, 0.76, 0.7)
Machine learning [62]	Accuracy neural network 85%
CNN [63]	Accuracy 75.53% to 90.87%

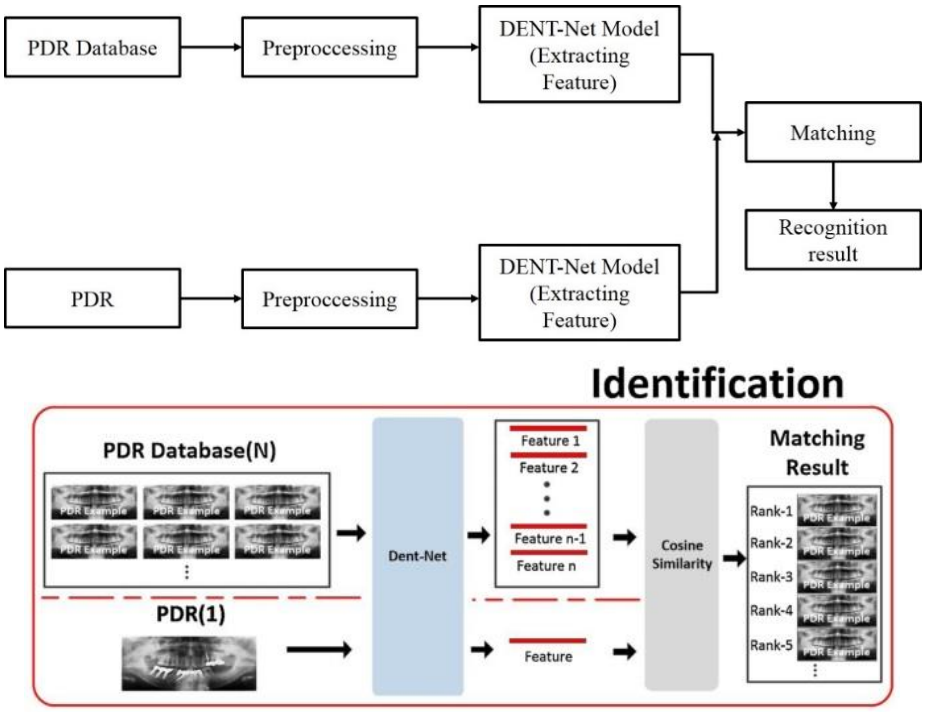


Figure 5. Identification diagram using teeth [60]

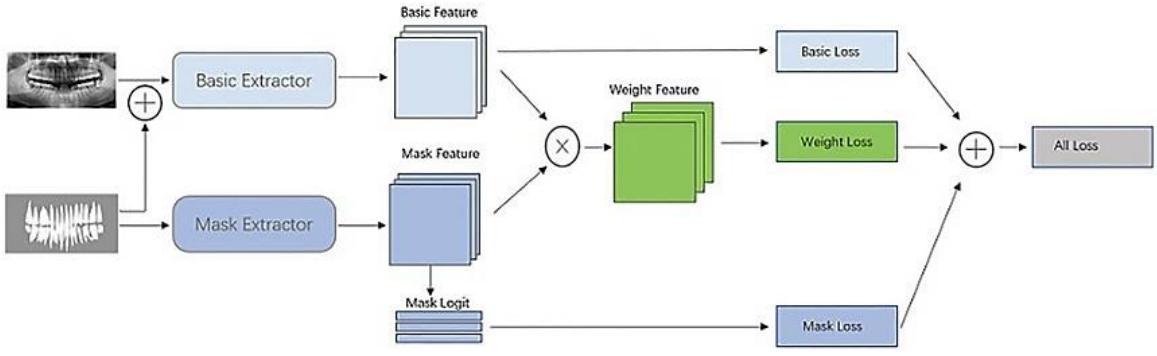


Figure 6. Identification based on teeth using CNN [63]

6. CONCLUSION

We aim to conduct a process of identifying reviews on radiographs. In comparison, the traditional method of individual identification is by measuring or matching teeth between antemortem and postmortem on panoramic radiographs. The process to do tooth matching automatically uses methods including ML, neural networks, deep learning, and CNN. The process to identify manually or semi-automatically by measuring mandibular parameters on panoramic radiographs either with standardized measuring devices or applications such as ImageJ, master view, Sidex software, and RadiAnt Dicom Viewer. Segmentation on radiographs mostly segments the teeth to the jaws or segments the mandible. The segmentation methods include conventional clustering or filtering, active contour, or CNN deep learning.

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