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Detection of the mandibular canal in orthopantomography using a Gabor-filtered anisotropic generalized Hough transform☆

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ABSTRACT

In this paper, we explore the possibility of applying the anisotropic generalized Hough transform (AGHT) enhanced with a Gabor based time-frequency filtering (GTF) for the determination of the mandibular canal in digital dental panoramic radiographs. The proposed method is based on template matching using the fact that the shape of the mandibular canal is usually the same, followed by a filtering of the accumulator space in the Gabor domain for a precise detection of the position. The proposed procedure consists of a detailed description of the shape of the canal in its canonical form and on preserving Gabor filtering information for sorting the hierarchy of location candidates after applying anisotropically the extraction algorithm. The experimental results show that the proposed procedure is robust to recognition under occlusion and under the presence of additional structures e.g. teeth, projection errors.

1. Introduction

The estimation of the mandibular canal is useful in detecting the nerve for inferior teeth called inferior dental nerve which is found inside it. While there are many research studies trying to visually identify the mandibular canal eg. [1,7,9], the aim of this work is to propose an automatic method based on the anisotropic generalized Hough transform filtered with a Gabor-based transform for marking the mandibular canal in dental panoramic radiography. The clinical motivation relies in the ground fact that these types of images are relatively cheap and easy to acquire compared with other types of imagistic investigations e.g. computer-tomography and they are still widely spread within the community of oromaxillofacial practitioners.

On one side, the **Hough transform** is a popular technique to extract features from an image. The method was patented in 1962 [5] for the detection of lines in photographs. The functioning of the algorithm lies in a proper choice of the parameters space for the set of lines on the plane. Consider the implicit equation of a line as expressed in [6]

$$f((\hat{m},\hat{c}),(x,y)) = y - \hat{m}x - \hat{c} = 0 \qquad (1)$$

where $\hat{m}$ and $\hat{c}$ are the slope and the intercept that characterize the line. Eq. (1) maps every pair of parameters $(\hat{m},\hat{c})$ to a specific line, a shape.

By swapping the roles of the parameters and the points and fixing one point, the equation defines all the lines that pass through the fixed point.

So, if we consider some points in an image, they will be collinear if we can find a parameter $(\hat{m},\hat{c})$ which satisfy (1) for all the fixed points.

Following [2], consider now a generic curve in analytic form

$$f(\boldsymbol{x},\boldsymbol{a}) = 0 \qquad (2)$$

where $\boldsymbol{x}$ is a point and $\boldsymbol{a}$ is a parameter vector. For every point we will find a hypersurface of parameters that satisfy (2). The curve will be detected in the intersection of these hypersurface. For example if we consider a circle

$$(x - x_0) + (y - y_0) = r_0^2,$$

due to the relation among x_0, y_0, and r_0, the number of free parameters is two.

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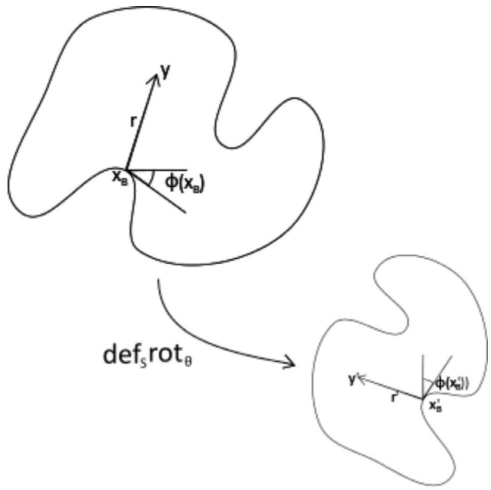

Fig. 1. Explanation for the notation used in the Hough transform method.

Every point (x, y) will produce a cone in the parameter space (x_0, y_0, r_0); if we consider three point on the plane, we can find the related circle as the intersection of these 3 cones.

Now we can add further information that can be extracted an image: the gradient and the tangent on the points of the edge. We can use the equation of the curve together with its derivative to find all the parameters which satisfy

$$\frac{\partial f}{\partial \boldsymbol{x}}(\boldsymbol{x}, \boldsymbol{a}) = 0 \tag{3}$$

or similarly

$$\frac{\partial y}{\partial x} = \tan\left(\phi(x) - \frac{\pi}{2}\right),$$

which is known since $\phi(x)$ is the gradient direction (see Fig. 1).

Going back to the example of the circle, fixing the gradient with the point means that the center must lie r_0 units along the direction of the gradient, so the number of free parameters reduces to one.

In order to develop a method for the recognition of a generic template in an image, [2] used the following parameters for a shape:

$$\boldsymbol{a} = \{\boldsymbol{y}, \boldsymbol{S}, \theta\} \tag{4}$$

where $\boldsymbol{y} = (x_r, y_r)$ is a reference point to represent the translations, $\boldsymbol{S} = (S_x, S_y)$ are scale values for the orthogonal shearing deformations, and θ is an angle that represents the rotations.

The reference point $\boldsymbol{y}$ is described in terms of a table, called the **R-table** (Table 1) of the template, of possible edge pixel orientations. The other parameters are described in terms of transformations of the aforementioned table.

The key for generalizing the Hough transform is to use the directional information. Given a template, i.e. a set of boundary points $\{\boldsymbol{x}_B\}$, a reference point $\boldsymbol{y}$ is chosen. After the discretization of the straight angle through a uniform partition $\{0, \Delta t, 2\Delta t, \ldots, N\Delta t\}$, for every boundary point the tangent direction $\phi(\boldsymbol{x}_B)$ is computed, then $\boldsymbol{r} = \boldsymbol{y} - \boldsymbol{x}_B$ is stored in the nth bin of the R-table if $\mod(\phi(\boldsymbol{x}_B), \pi) \in [(n-1)\Delta t, n\Delta t)$. This choice of using the angle modulus π will be made clear later.

Usually, to control the error in the computation of $\boldsymbol{r}$, the barycenter of the boundary point is chosen as reference point and $\boldsymbol{r}$ is stored in polar coordinates.

We obtain a structure in the form

Given this simple structure, if we define the rotation and shearing operators, i.e. rot_θ and $def_{\boldsymbol{S}}$, we can build the following procedure to detect the template in the set of edge points of any image

Table 1
R-table.

Bin	Points
1	$\{\boldsymbol{r} \mid \exists\, \bar{\boldsymbol{x}} \in \{\boldsymbol{x}_B\}\ s.t.\ \mod(\phi(\bar{\boldsymbol{x}}), \pi) \in [0, \Delta t[\}$
2	$\{\boldsymbol{r} \mid \exists\, \bar{\boldsymbol{x}} \in \{\boldsymbol{x}_B\}\ s.t.\ \mod(\phi(\bar{\boldsymbol{x}}), \pi) \in [\Delta t, 2\Delta t[\}$
⋮	⋮
N	$\{\boldsymbol{r} \mid \exists\, \bar{\boldsymbol{x}} \in \{\boldsymbol{x}_B\}\ s.t.\ \mod(\phi(\bar{\boldsymbol{x}}), \pi) \in [(N-1)\Delta t, N\Delta t]\}$

1. Fix a deformation $\boldsymbol{S}$ and a rotation θ.
2. Compute the gradient of the edge points $\phi(\boldsymbol{x}_e)$.
3. Select the Bin in the R-table corresponding to $def_{\boldsymbol{S}}(rot_\theta(\phi(\boldsymbol{x}_e)))$.
4. For every $\boldsymbol{r}$ in the selected Bin, report an occurrence of $\boldsymbol{y}' = \boldsymbol{x}_e + def_{\boldsymbol{S}}(rot_\theta(\boldsymbol{r}))$ as possible reference point.

In this way, we find the edge point that satisfy the non-analytic version of (2) and (3). The space of occurrences for the reference point is called **Accumulator Space**.

On the other side, the main tool for time-frequency analysis is the **Short-Time Fourier Transform** (STFT), defined for functions $f, g \in \boldsymbol{L}^2(\mathbb{R}^d)$ at $\lambda = (\alpha, \beta) \in \mathbb{R}^{2d}$ by

$$V_g f(\lambda) = V_g f(\alpha, \beta) = \langle f, M_\beta T_\alpha g\rangle = \langle f, \pi(\lambda) g\rangle \tag{5}$$

where $T_\alpha f(t) = f(t - \alpha)$ is the translation (time shift) and $M_\beta f(t) = e^{2\pi i \beta \cdot t} f(t)$ is the modulation (frequency shift). The operators $\pi(\lambda) := M_\beta T_\alpha$ are called **time-frequency shifts** and the set $\Lambda = \{\lambda;\ \lambda = (\alpha, \beta) \in \mathbb{R}^d \times \widehat{\mathbb{R}}^d\}$ is a **lattice**.

Gabor analysis [3,8,10] is a discrete version of the STFT and it is concerned with the representation of signals or images using a series consisting of time-frequency shifted copies of the given atom g. The **Gabor system** for analysis $\mathcal{G}(g, \Lambda) = \{\pi(\lambda) g;\ \lambda \in \Lambda\}$ over the lattice Λ consists of the translated and modulated versions of g, and it forms a **frame** for the space $L^2(\mathbb{R}^d)$, if and only if there exist $0 < A \le B < \infty$ (**frame bounds**) with

$$A||f||^2 \le \sum_{\lambda \in \Lambda} |\langle f, \pi(\lambda) g\rangle|^2 \le B||f||^2 \quad \text{for every} \quad f \in L^2(\mathbb{R}^d), \tag{6}$$

With the interpretation proposed in Section 3.1, we will use the direct Gabor transform for ranking in the accumulator space of the AGHT.

2. Recognition of the pattern: the case of mandibular canal

In the previous section, we described a common way to detect a template using the AGTH. Problems arise when we have to deal with real images which could be corrupted by noise. That is the case of radiography where the structure of a bone is not well defined and where some part of the bone which would be detected can be disguised - even from the human eye - with unwanted details.

The position of the mandibular canal is described by medical indications as follows: the canal starts at the mandibular foramen in the middle part of the vertical ramus. It continues through the mandibular bone and ends in the menton foramen between apexes of the two inferior premolars.

This indication can become misleading if we analyze radiograph of a patient who has lost some teeth.

Any surgical intervention in the mandibular area must prevent any nerve injury. The injury of the nerve would result in prolonged local and lower lip anesthesia for a minimum period of six weeks. Estimating the position of the mandibular canal means knowing the position of the nerve and by this the surgeon can estimate the risks and to adapt the surgical procedure to the individual case.

In our test we used Fig. 2 to extract the template of the canal. The recognition performs well on the same panoramic radiograph

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