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KNOWLEDGE-BASED IMAGE PROCESSING WITH APPLICATION TO THE LANDMARKING OF CEPHALOGRAMS

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RESUME

Est considérée ici une classe de problèmes en traitement d'images où certaines caractéristiques géométriques d'un objet connu doivent être estimées; sur chaque image particulière, cet objet présente de petites déformations par rapport à un idéal. Une méthode générale est proposée pour l'extraction, basée sur des connaissances a priori, de certaines lignes ou contours de l'image. Ce modèle consiste en les étapes suivantes :

- préfiltrage;
- détection de contours;
- poursuite de sommets se servant de connaissances a priori.

Les connaissances de chaque ligne codées dans l'algorithme, sont les suivantes :

- sa position approximative;
- les conditions de début et fin;
- le nombre de segments et leurs caractéristiques.

La méthode ci-dessus est appliquée à l'extraction de points caractéristiques de céphalogrammes (radiographies latérales de la tête).

SUMMARY

In this paper we consider a class of problems in image processing where some relevant features must be estimated on a known object that presents small deformations relative to an ideal. A general procedure is proposed for a priori knowledge-based extraction of certain lines or contours from the image. This model consists of the following steps :

- prefiltering;
- edge detection;
- knowledge-based line following.

For each line the knowledge implemented is :

- its approximate position;
- the conditions under which it starts and stops;
- the number of segments and their characteristics.

The above approach was applied to the extraction of characteristic points, or landmarks, on a lateral cephalogram (head x-ray).

1. INTRODUCTION

When it is desired to quantify geometrically an object, it is common practice to specify the distances between characteristic points defined on the object in terms of lines and edges. Two extreme examples of such geometrical measurements are the specifications of the dimensions of machine parts, on the one hand, and anthropometric measurements on the other. In the first case the actual distance is to be found within a specified tolerance span around a standard value. In the case of anthropometric measurements the expected variations around the new value are much larger since the variability of biological shapes is in general important. The procedure described in this paper is appropriate for the extraction of geometrical measurements from images. All of these must represent an object known a priori, abstractly defined in that all the objects are deformed versions of an ideal. The aim of the processing is to estimate the exact shapes of certain lines or edges in the images. Examples of the class of images and problems our work addresses are images representing biological objects, where the shape of a line or an edge must be estimated for classification or diagnostic purposes; photographs or x-rays of industrial parts, for quality control; recognition of human faces through estimation of anthropometric parameters.

The proposed model consists of the following two steps :

- simplification of the image in order to render it easier to process; in particular, the low frequency components (background) must be eliminated;
- a knowledge-based line-following algorithm, based on a production system with organized sets of rules and a simple interpreter.

The application of this general system in the particular case of cephalometric landmarks extraction will be presented.

2. GENERAL KNOWLEDGE-BASED IMAGE PROCESSING SYSTEM

2.1 SIMPLIFICATION OF THE IMAGE

The interesting features of the image are the lines and edges; hence the simplification will consist of the transformation of the image into a pattern of lines. When the image is very noisy, which is the rule in the real world, a prefiltering is indicated before the edge detection itself.

2.1.1 Prefiltering

There are two alternate philosophies for prefiltering before an edge detector. One may choose to enhance the edges without significantly enhancing the noise, or to filter out some of the noise while preserving the edge information. Histogram equalization and extremum sharpening belong to the first approach. Median filtering, to the second. The latter method was preferred over the others, as the noise they create renders the line following much more difficult. On the contrary, median filtering reduces impulse noise without blurring lines or edges. It also smoothes sharp projections or indentations that are small relative to window size, which limits this parameter.

2.1.2 Edge detection

Four operators were tried and compared : the Laplacian, two non-linear gradient operators, Sobel's and Prewitt's, as well as the Kirsch operator [1] and the Mero-Vassy (simplified Hueckel) operator [2]. The Laplacian and Kirsch operators are not suited for posterior line following : the former enhances noise enormously, and the latter does not give a pattern of lines.

On the other hand, the Sobel, Prewitt and Mero-Vassy operators all transform the prefiltered image into the desired pattern of lines. The Mero-Vassy operator is however slightly superior to the others and was therefore chosen.

2.2. LINE FOLLOWING ALGORITHM

The knowledge-based algorithm is based on a general purpose line-follower, non knowledge-based, which can be described as follows : two thresholds are computed on the basis of the histogram of the picture [3]. The higher threshold defines the intensity of a pixel which could be on a line. The lower threshold defines the intensity below which a line cannot be followed. The image is scanned until a pixel with a suitable intensity is found. The line it is on is then followed in both directions.

2.2.1 Knowledge about the line

The relevant pictures are all deformed versions of a reference object. However, the deformation function of each is unknown, hence the knowledge about each constituent of the image cannot be described in terms of coordinates in a frame of reference. We have chosen to divide it into categories of knowledge, each corresponding to a characteristic of a particular line :

- position : the line must first be found. All lines in the pictures have more or less fixed positions relative to one another, which implies that finding the next line is facilitated by determination of the previous ones. The first lines to be found are generally the exterior lines that bound the object, as these are easier to track. These help finding the interior lines.
- Conditions under which the line starts and stops.
- Number and characteristics of the constituting segments : a line is modelled as formed of straight segments separated by

abrupt changes of direction. Each segment has a number of characteristics :

- its approximate length;
- its approximate orientation;
- the conditions under which it stops;
- the amount of noise around it, which corresponds to how well the line detaches itself from the background.

2.2.2 Knowledge-based line follower

We use a knowledge-based line-tracker guided by a reference map [4]. The map is initialized by a planning step [5] : with simple operations, i.e. analysis of the result of cuts and projections, it is possible to determine the gross proportions of this particular object, for example the rough position of the exterior lines. This map is progressively updated as more lines are found.

The algorithm uses a production system organized around the general purpose line-following algorithm. This form of a knowledge-based system was chosen because it can be defined in a natural fashion, which renders the algorithm easy to write and subsequently read. For each line, the algorithm tries to reach sequentially a number of goals, for which it fires sets of rules from a structured database. The modular sets of rules correspond to each of the categories of knowledge chosen previously.

The first set of rules is used to guide the search for the lines.

When the algorithm positions itself on a line, there is a set of start and stop rules for each segment, one for the way to choose the next pixel, including if there is an intersection, and one to decide if the chosen pixel is correct or has to be replaced, and by which other pixel. Three steps are performed in order to find the next pixel. Eight discrete directions are defined on the digitized image. The steps are the following :

- sorting the three candidate pixels (pixels within plus or minus 45 degrees of the direction between the previous and the current pixel) by order of increasing intensity; call the maximum intensity pixel max and the intermediate one, next;
- comparing the intensities of max and next, and determining if there is an intersection with the law :
  if (next/max>threshold) then intersection
- if there is an intersection, choosing the correct successor with appropriate rules; if there is no intersection, the successor is max.

A third set of rules establishes the stop conditions of the line.

The last set of rules is used once the line has been completely tracked to decide on its correctness and what parameter to modify before re-tracking it.

The interpreter is simple : it follows the logical path between these sets, starting with 1, then applying 2 and 3 at each pixel. Then 4 when the line is completely tracked. There is one conditional rule for each action. The conditions to be satisfied are different for each line. The control strategy is mostly irrevocable, i.e. the line is traced without backtracking, but the result of the tracking is questionned and the line is possibly retraced. after modification of certain parameters.

On Fig. 1, a flowchart of the line-follower is shown.

3. APPLICATION TO THE LANDMARKING OF CEPHALOGRAMS

The knowledge-based image processing system previously explained has been applied to the landmarking of lateral cephalograms. Cephalograms are head x-rays (Fig. 2 shows the digitized version of such an x-ray); on these, orthodontists have defined a number of characteristic points or landmarks. The positions of these various points is used as a diagnostic aid. As the landmarks are defined relatively to characteristic lines (see Fig. 3) we can design a knowledge-based algorithm that will extract the shapes of these lines from the x-ray. Simple computations will then give the positions of the landmarks.

The first operation performed on the digitized x-ray is median filtering (Fig. 4 is the result of a 3x3 operator). The homogeneous regions are rendered more homogeneous, and contours are slightly smoothed.

The edge detector (Mero-Vassy operator) is then applied, as seen on Fig. 5. The image is transformed into a pattern of lines.

We can now apply the knowledge-based line-following algorithm. The results, superimposed to the edge detected version of the x-ray, is shown on Fig. 6.

The positions of the landmarks can then be computed (Fig. 7). Some points are missing, because of the poor quality of the digitization instruments : the lines these points are defined with were not present on the digitized x-ray.

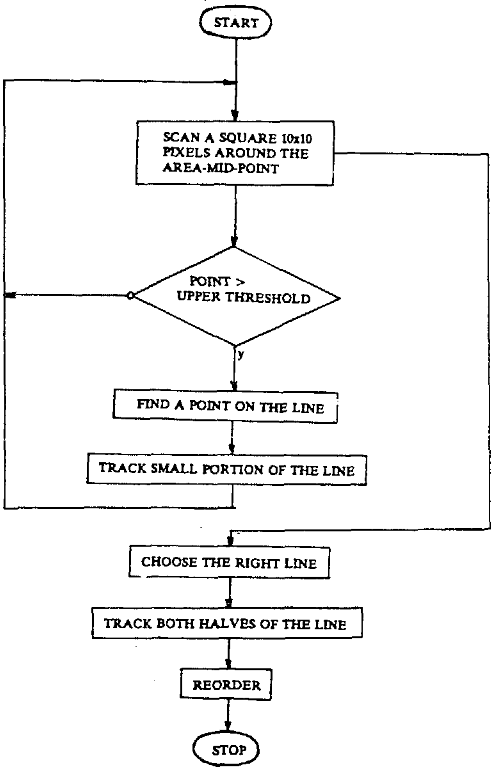

Fig. 1. Knowledge-based line following

Fig. 2. Digitized x-ray

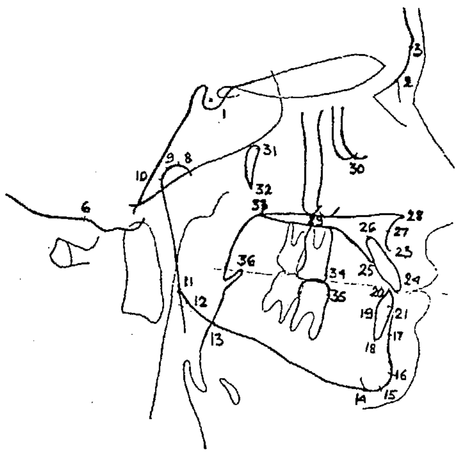

Fig. 3. Outline of the head with the landmarks

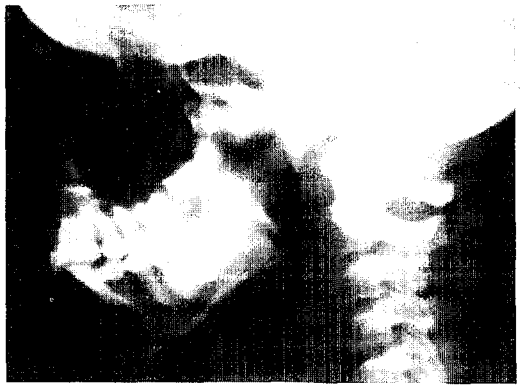

Fig. 4. Median filter

Fig. 5. Edge detector

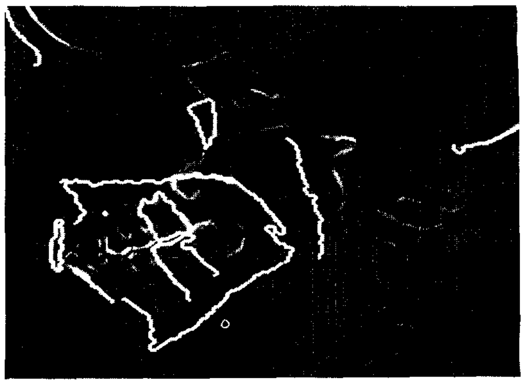

Fig. 6. Knowledge-based line following

4. CONCLUSIONS

We have presented a model for knowledge-based image processing for a certain class of problems : the important characteristics of the images involved are the lines and the edges of the objects, and it is desired to estimate the exact shape of those lines and edges. The processing is divided in two steps :

- transformation of the digitized image into a pattern of lines; this involves a prefiltering followed by an edge detection;
- extraction of the desired lines with a knowledge-based line follower.

This model was applied to the landmarking of cephalograms. The results are good, provided the lines or edges which are desired are sufficiently apparent. When this is not the case, the system's specificity must be improved, in particular in tayloring the knowledge implemented in the algorithm to the data processed.

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