Multi-Scale Detection of Curvilinear Structures with High Contour Accuracy

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Abstract

The detection of lines is an important low-level operation in computer vision that has many applications. Most of the existing line detectors do not take into account the width of the lines to be detected. In this paper, a novel multi-scale approach to curvilinear features detection with high contour accuracy is presented. A line detector at different orientations is applied to a multi-scale decomposition of the original image in order to obtain scale-orientation signatures at each pixel, which can be used to detect seeds. The contours of the linear structures are fitted by growing these seeds. The performance of the algorithm is evaluated by its application to recognize marbling in Iberian ham images.

1. Introduction

The detection of curvilinear structures, often simply called lines, is an important low-level operation in computer vision that is commonly used as a previous step in many image analysis applications, e.g. medical [1], [2] and aerial [3] imaging.

The previous work on line detection can be classified into two categories. Firstly, several methodologies are only concerned with the detection of the central line position [3], [4], [5]. These methods are highly dependent on the width of the lines to be detected, their parameterization is usually embedded and/or they are not fully automatic.

Secondly, few approaches to line detection consider extracting the line width along with the line position [6], [7]. To achieve this goal, some authors combine a multi-scale decomposition [8] of the original image with differential operators (typically differences of neighboring pixels), which are applied to each level of the decomposition.

In this paper, a novel multi-scale approach to curvilinear features detection with high contour accuracy is presented. A multiresolution decomposition is combined with the application of line detectors at different orientations, resulting in a scale-orientation signature for each pixel of the original image. From this information, a coarse estimate of the line width and orientation is obtained and utterly refined by region growing techniques. The algorithm is fully described in section 2. Section 3 presents the application of this methodology to a food technology problem, followed by a conclusion in the last section.

2. Methods

The proposed fully automatic algorithm follows a multi-scale scheme which consists of three steps: i) multi-scale decomposition of the original image, ii) application of line detectors at different orientations to each level of the decomposition, resulting in a set of seeds that represent a coarse estimate of the lines present in the original image, and iii) contour fitting of the above seeds by region growing techniques.

2.1. Multi-scale decomposition

In the sequel, we use the term level to denote an image at a specific scale. The original image (ground level) corresponds with level 0 and the top level is at level L. The decomposition, thus, contains L+1 levels at increasing scale. The simplest multi-scale decomposition is the d-dimensional pyramid [8], which is created by sub-sampling level n to derive level n+1. This is done by straight averaging of 2d pixels (the children) to form one blurred pixel (the parent). The major drawback of the simple pyramid is the emergence of spurious details at the higher levels. This approach was used in previous work [10].

Many improvements have been proposed to the conventional pyramid approach. Examples are the Gaussian pyramid [8], where the averaging is replaced by a better discrete representation of the Gaussian kernel, the morphological pyramid, constructed by scaled morphological operations, and the wavelet pyramid [9].

2.2. Line detection

Different sized lines are extracted by applying line detectors to the subsequent levels of the multi-scale decomposition, resulting in a scale-orientation signature for each pixel of the original image. The maximum response at a certain scale and orientation will indicate the correct line width and direction at a pixel level. The following generic line detectors, which can be tuned to detect lines in a certain range of widths, are considered:

2.2.1. Line operator. The line operator improves the line signal to background noise ratio by taking the average gray level of the pixels lying on an orientated local line passing through the target pixel and subtracting the average intensity of all the pixels in the kernel neighborhood. The line strength (output of the operator) is compared for n orientations and line direction is obtained from the orientation producing the maximum line strength.

2.2.2. Directional morphology. The detection proceeds initially by application of a standard non-directional opening using a circular structuring element. The resulting coarse structure image is subtracted from the original image and the method continues by application of a directional opening using an oblong structuring element. The opening is performed with the oblong orientated at n equidistant directions, and the direction producing the highest response provides the line strength and orientation [11].

2.2.3. Orientated bins. The local neighborhood of the target pixel is divided into n angular bins. The resulting line strength is based on the number of pixels and their relative intensity which fall into a certain orientated bin. The relative intensity is determined by the total intensity of all the pixels per orientated bin divided by the number of pixels in those bins. Line strength is given by the difference between the maximum relative bin intensity and the relative intensity of the whole neighborhood. The local line orientation is given by the bin with the maximum relative intensity.

2.3. Region growing

From the previously obtained information, a set of seeds representing the skeleton of the linear structures is generated by thresholding. These seeds can be refined by region growing techniques.

Region-oriented approaches to region growing rely on the postulate that neighboring pixels within one region have similar gray-level. On the other hand, boundary-oriented approaches rely on the postulate that pixel values change rapidly at the edges of regions. In a previous work [10] we compared the performance of region-oriented techniques based on fixed thresholds (obtained by Otsu, Tsai and Kapur methods [12]), and a boundary-oriented technique which uses the zero-crossings of the original image as watersheds for the expansion of the seeds. In our particular application, the best results were obtained by Otsu region growing.

In the present work we consider another region-based approach: the seeded region growing (SRG) algorithm [13], which consists of the expansion of the seeds by adding neighboring pixels because of their "similarity" in terms of intensity to the corresponding seed.

3. Application to food technology

In this section we illustrate the proposed algorithm by describing its application to recognize marbling in Iberian ham. We report the results obtained by evaluating its performance in this particular task. These results will be used for further research on the classification of Iberian ham sensorial quality.

3.1. Iberian ham overview

Iberian ham is one of the most appreciated dry-cured meat products in Spain. Its sensorial characteristics are basically due to high intramuscular fat content and marbling, i.e. number, position, shape and size of intramuscular fat streaks. Currently, chemical processing is the only proved way to determine fat level of cured Iberian hams, but this technique is tedious, destroying and does not offer any information about fat distribution [14]. Evaluation of Iberian ham sensorial quality is performed by trained human testers. The design of a non-destructive methodology to classify Iberian ham from the viewpoint of sensorial quality, independently of the subjective and variable criteria of testers, would be of great interest to Iberian ham industries.

Intramuscular fat streaks can be considered as orientated line patterns. Our current attempts are to investigate the relationship between objective physical parameters of the streaks and Iberian ham sensorial quality. To achieve this goal, not only the detection of fat streaks is important, but also the identification of their contours with high precision, in order to calculate parameters as the relative size of one streak in relation to others, streak shape descriptors, etc.

3.2. Results

Validation set. 15 Iberian ham slices from the biceps muscle have been digitized with a general purpose scanner at spatial resolution of 100 pixels per inch and gray-level resolution of 8 bits depth. The area in pixels of the slices ranges from 131.109 to 203.779, i.e. 57 cm2 to 72 cm2. All visible intramuscular fat streaks have been annotated by an expert in food technology. The total number of streaks annotated per image ranges from 21 to 47 (up to 454 in the 15 images) and their areas range from 5.314 to 20 pixels, i.e. 343 mm2 to 1.3 mm2. Figure 1 shows a region extracted from an original Iberian ham image and its correspondent set of annotated fat streaks, represented as white regions against a black background.

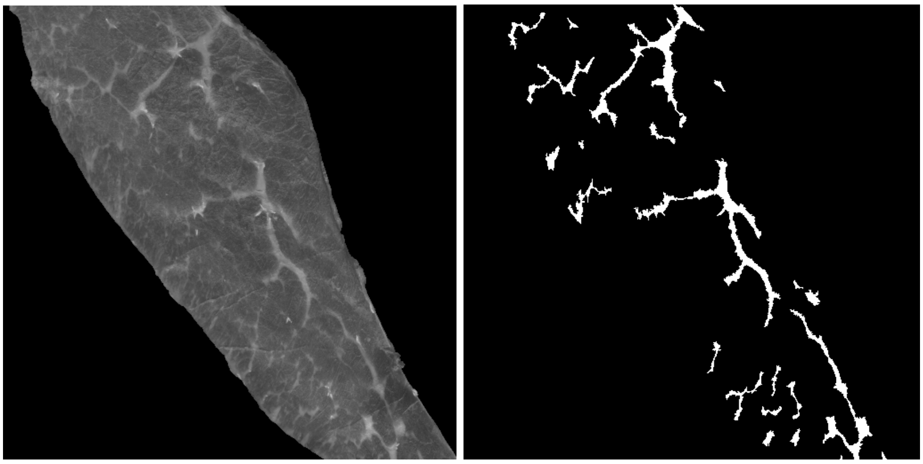

Figure 1. Region extracted from an original Iberian ham image (left) and correspondent set of annotated fat streaks (right).

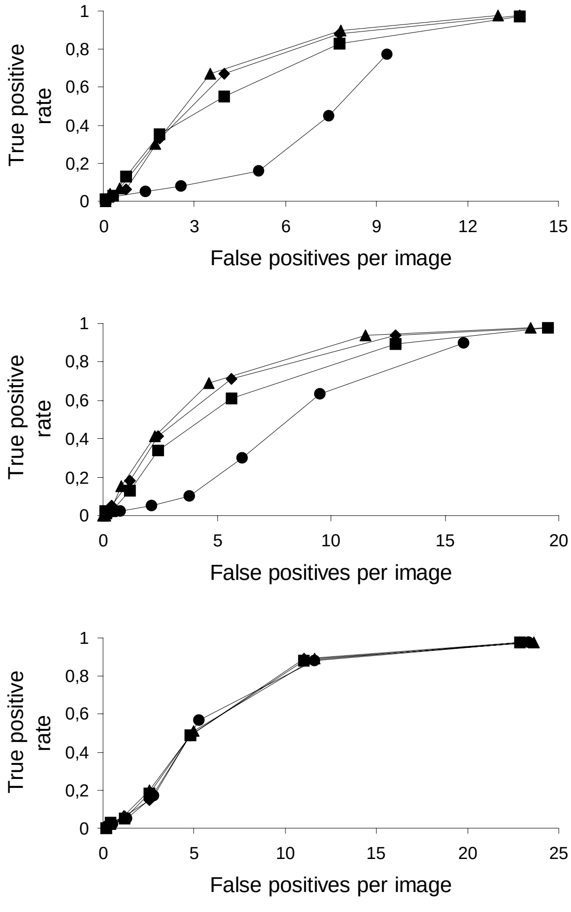

Figure 2. Comparison of fat streak detection performance for the line operator (upper), orientated bins (middle) and directional morphology (lower) detectors combined with seeded region growing. The following multi-scale decompositions are applied: Gaussian (♦), morphological (■), wavelet (●) and simple pyramid (▲).

The proposed method has been applied to our database of digital images. The widths of the features of interest are typically between 3 and 30 pixels. So, the active region of the line detectors is tuned to 3 pixels width and they are applied at 8 equidistant orientations to a 5-level pyramid decomposition in order to ensure detection of all features in that range of widths. The results obtained are compared by FROC curves [15], where the true positive rate is graphed against the number of false positive streaks per image. We assume that a detected region is counted as true positive when its area in pixel units is at least 50% overlapped with an annotated region and vice-versa. The true positive rate is pondered by RA/RT, where RA is the detected streak area and RT is the total area of annotated streaks in the image.

Figure 2 shows the results of applying the proposed method with the line operator (LO), directional morphology (DM) and orientated bins (OB) detectors at different scales and orientations. The curves obtained reveal that DM is independent of the multi-scale decomposition, while LO and OB achieve the best scores when simple or Gaussian pyramid decompositions are applied.

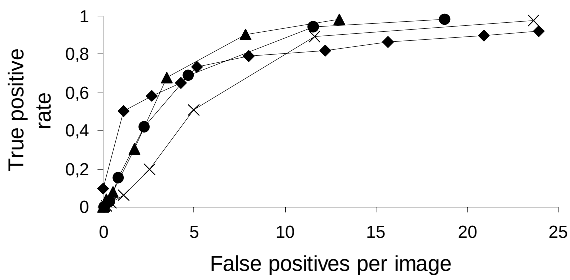

Figure 3. Comparison of fat streak detection performance for the line operator with Otsu region growing (♦) and the line operator, directional morphology and orientated bins with seeded region growing (▲, ×, ●, respectively).

Figure 3 compares the performance of the proposed algorithm from the viewpoint of the region growing technique applied. The multi-scale decomposition considered in all cases is the simple pyramid. In our previous experiments [11], the best scores were obtained by LO combined with Otsu region growing. In this study, LO-SRG reveals as the best combination, being DM-SRG the worst.

3.3. Discussion

From the graphs shown, the number of false positives is a priori high for a significant sensitivity. Figure 4 shows a quantitative analysis of the sizes of all detected, missed (false negative) and noise (false positive) regions after applying the best combination (line operator and seeded region growing). Each bin contains regions whose size is smaller than a certain area, and the bins are ordered by this area. The graphs show that missed and false positive regions are predominantly smaller in size than detected regions. The addressed method most often misses small regions (on the order of 1.000 pixels or less) and most of the false positives are also concentrated in the lowest bins. It is important to emphasize that the largest regions are always correctly classified.

On the other hand, it can be noted that the number and size of false positives and false negatives is comparable. This fact can be used to estimate the total area of fat streaks in the original image (in pixel units) as the sum of true and false positive areas and calculate the relative fat percentage contained in the largest streaks, which could be a factor to predict Iberian ham sensorial quality.

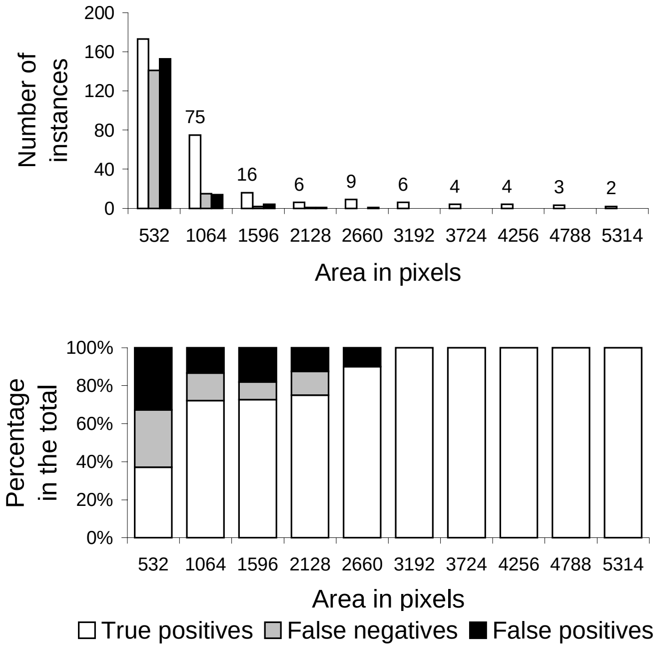

Figure 4. Number (upper) and percentage (lower) of true positives, false negatives and false positives for the method based on simple pyramid decomposition, line operator and seeded region growing.

4. Conclusions

A novel method to detect curvilinear structures with high contour accuracy has been described. Its straightforward application to recognize marbling in Iberian ham has been evaluated, obtaining better results than those found with other previous approaches. Since the algorithm is explicitly adjustable, we believe it could be useful in other applications, which are currently being studied.

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