Color Thinning with Applications to Biomedical Images

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Abstract. A scheme for cell extraction in color histological images based edge detection and thinning is considered. An algorithm for thinning of color images is proposed that is based on thinning of pseudo gray-scale image. To extract accurately gray-scale levels, we propose a new coordinate system for color representation: system PHS, where P is a vector of color distance, H is a hue (chromaticity), S is a relative saturation. This coordinate system allows one to take into account specifics of histological images. Comparison of image thinning in other coordinate color systems is given that shows the image thinning in PHS system produces a rather high-quality skeleton of the objects in a color image. The proposed algorithm was tested on the histological images.

Keywords: image thinning, color spaces, biomedical images

1 Introduction

Color image processing is rapidly developing area of research and applications due to widely used color image acquisition devices now. However, many algorithms that have been successfully used in grey-scale and binary image processing are not immediately applicable to color images.

In difference with gray-scale images where each pixel is represented by three coordinates (x, y and brightness), color image is exemplified by five coordinates: three characteristics of the color (hue, luminance, saturation), and two coordinates of the spatial location of the object (x, y). Mutual influence of these coordinates is very complex and its analysis is usually time-consuming. Based on color coordinates, we may consider that in color image we deal with three

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gray-scale images. Correspondingly it is possibly to build color image processing algorithms proceeding from corresponding gray-scale algorithms. However, we should answer on the question: what does correspond to a grey level in a color image ?

One of the most significant operations in image processing is thinning that transforms original "thick" object in lines of one-pixel thickness. Thinning is very well developed for binary images [8]. During last decades, there appeared quite many papers with algorithms for thinning of grey-scale images [1,3] but there are no practically algorithms for thinning of color images. However, color always gives specifics in image processing and object recognition that leads to necessity to develop special algorithms for color image processing.

Here, we consider processing of color histological images that usually contain cells, kernels, etc. Cells can be classified by using their shape and structure. The cell shape can be treated as almost round-shaped (circular-based primitive) and not elongated. The cell structure is characterized by its kernels and kernels' position. Another important cell feature is its position in a tissue.

It is practically impossible to select or develop automatic segmentation methods that can automatically extract required cells and compute their characteristics. That is why most of the papers consider particular features of cell images and methods of their segmentation. Among the main cell segmentation approaches are those based on edge detection, thresholding, snakes, Hough transform, morphological operations, neural networks [10,4,6].

There are several papers analyzing color cell images [11,2]. In paper [5], for cell image segmentation, RGB space and Lab space are combined. By this method, both the nucleus and cytoplasm of cancer cells can be separated from background. Then, the candidate cancer cells are selected using some morphological features of nuclei, the purpose of this step is to pick out most of the non-cancer cells and leave a few doubtful cells for further verification, therefore improving the efficiency of the whole recognition process. As the last step, for all the candidate cells, some statistic parameters in different color space are calculated, which are used as features for recognition. Paper [7] proposes to segment color cell images by Constraint Satisfaction Neural Network (CSNN) algorithm. This is accomplished by incorporating in the CSNN algorithm multiresolution scheme using pyramid structure.

The results of segmentation often depend on a cell image quality and when difference between cell or kernel and background is small, most of the methods do not work properly. We analyzed a wide range of cell images and consider that cell shapes can be correctly extracted through edge detection and thinning approach.

In this paper, we propose the algorithm for thinning of color images that is based on thinning of pseudo gray-scale images. To extract accurately gray-scale levels, we propose a new coordinate system for color representation and propose algorithm to thin separate gray-scale images. Examples of thinning for color histological images are given.

2 Coordinate System for Thinning Histological Color Images

Pseudo-colors usually require introduction of special coordinate system where they will be reflected. From other side, new coordinate system should reflect specifics of images and algorithms. Such as we orient to morphological algorithms and histological images that have special features, we will build the corresponding coordinate system.

One of the most important characteristics of an object in a histological color image is its chromaticity. If image fragments have an abrupt jump in chromaticity, they are either the object or its part. However, chromaticity almost does not influence the object topology. From other side, if we process one coordinate instead of two, we get a twofold gain in the speed. In most operations of the thinning, the processing of the image consists of many iterations, hence this gain is essential.

Thus, processing of vector of color distance between the origin of coordinates and the desired point can be an advantageous. It equals the sum of the vectors of the luminance and saturation or the sum of the basis RGB vectors which directly specify the color. Therefore, it contains information about both the luminance and saturation and is a gray-scale value, which is most appropriate for the thinning on color images. That is why we propose to introduce the coordinate system where one of the axes is the vector of the color distance, and another, the quantity which features chromaticity.

Let us consider a cylindrical coordinate system whose central axis is a result of the vector summation of axes of RGB system and has a meaning of the monochromatic component. First of all, it should be noted that chromaticity, which is characterized by the angle of rotation, is an independent feature of the object, whereas saturation and luminance depend upon the external conditions. Thus, the most efficient for analysis will be employment of the vector of the color distance, which is equal to the sum of vectors of luminance and saturation or the sum of the basis RGB vectors, which directly exemplify the color. It remains to introduce a quantity, which will characterize a correlation of the luminance and saturation. Such a quantity is the angle between the vector of the color distance and central axis of the frame of reference. This quantity has a meaning of the relative saturation and should not vary during image processing. The purpose of this quantity is to reconstruct the relation of the luminance and saturation in inverse transformations. Thus, in the following, we shall call this spherical system of coordinates as PHS, where P is the vector of the color distance, H is hue (chromaticity), S is relative saturation.

In order to obtain a desired system, it is necessary to carry out two rotations of the coordinate axes about 45°. We have carried out a rotation in the plane RB, and then in the plane RG. This resulted in the following transformations of the coordinates:

$$\begin{cases} Z = \frac{1}{2}(R + \sqrt{2}G + B) \\ Y = -\frac{\sqrt{2}}{2}(R - B) \\ X = -\frac{1}{2}(R - \sqrt{2}G + B). \end{cases}$$

Passing from Cartesian coordinates ZYX to the spherical ones, we obtain PHS:

$$\begin{cases} P = \sqrt{R^2 + G^2 + B^2} \\ H = \arctan\left(\frac{\sqrt{2}(B-R)}{\sqrt{2}G-R-B}\right) \\ S = \arccos\left(\frac{R+\sqrt{2}G+B}{2P}\right). \end{cases}$$

For operations of the gray-scale morphology in this system, P is used. For separation, H is employed, and S is always invariable because this value corresponds to the relation of the luminance and saturation.

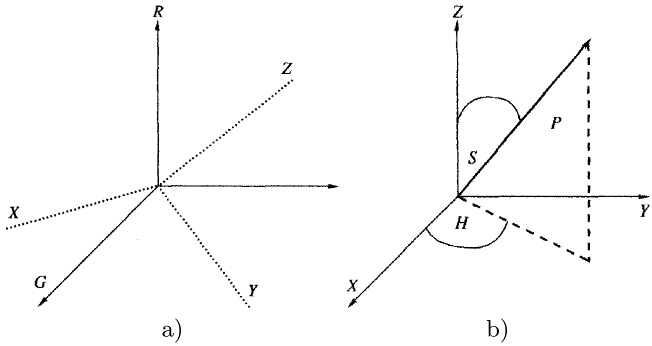

Fig. 1. Coordinate systems: a) RGB and ZYX systems, b) ZYX and PHS.

Thus, we have obtained a system of color coordinates, which can be profitably employed for thinning of color images.

3 Thinning of Color Images

We propose to use pseudoimage, each pixel of which corresponds to the vector of the color distance of initial image. Pseudoimage corresponds to a gray-scale image, thus we can apply our algorithm of gray-scale thinning [9] for thinning of color image.

In the pseudoimage, which consists of the vector of color, all gray-scale levels are analyzed simultaneously and radius-vector of the distance of the color of a pixel which satisfies the above-mentioned conditions is diminished by 1. In order that diagonal pixels would not be processed twice during one run, they should be marked; for this purpose, an additional array is generated with dimension that corresponds to the dimension of the image. After the cycle is passed, the array is zeroed. This guarantees that pixels are processed only once in a single cycle. The number of iterations of tail removal is equal to the maximum length of the branches, which should be removed.

When each cycle is executed, the branches that arise due to roughness of the object are removed. The following condition is checked for every pixel:

If ($p0 >= x$ OR $p1 >= x$ OR $p2 >= x$ OR $p3 >= x$ OR $p4 >= x$ OR $p5 >= x$ AND $p6 < x$)
AND ($p2 >= x$ OR $p3 >= x$ OR $p4 >= x$ OR $p5 >= x$ OR $p6 >= x$ OR $p7 >= x$ AND $p0 < x$)
AND ($p4 >= x$ OR $p5 >= x$ OR $p6 >= x$ OR $p7 >= x$ OR $p0 >= x$ OR $p1 >= x$ AND $p2 < x$)
AND ($p6 >= x$ OR $p7 >= x$ OR $p0 >= x$ OR $p1 >= x$ OR $p2 >= x$ OR $p3 >= x$ AND $p4 < x$) then the central pixel is diminished by 1.

Each pixel in the image has eight neighbors, which are numbered according to the following scheme (Fig. 2).

p3	p2	p1
p4	X	p0
p5	p6	p7

Fig. 2. 8-neighborhood of a central pixel x

The result is a skeleton of the image, which has fragments with different hues and smoothly varying luminance and saturation.

4 Binarization of Color Skeleton

The binarization is carried out at a single run of the image. If the pixel to be processed has at least one of the four neighbors ($p0$, $p2$, $p4$, $p6$) with a radius-vector of the color distance less than its own, or all diagonal octo-neighbors have a radius-vector with the color distance less than its own, its value is set to 1, otherwise to 0. That is:

$$X = \begin{cases} 1, & \text{if } p0 < X \text{ OR } p2 < X \text{ OR } p4 < X \text{ OR } p6 < X \text{ OR} \\ & (p1 < X \text{ AND } p3 < X \text{ AND } p5 < X \text{ AND } p7 < X) \\ 0, & \text{otherwise.} \end{cases}$$

5 Experimental Results

The developed algorithm has been applied for processing of histological images of a human liver, where the cell nucleus had to be extracted (Fig. 3). The algorithm of cell extraction includes cell edge detection for which Sobel gradient has been applied first (Fig. 3b). Then, color thinning allowed us to obtain one-pixel thickness contours of the cell edges (Fig. 3c). Subsequent hue binarization allowed us to extract precise contours of the cell nucleus (Fig. 3d).

Practical verification has demonstrated that the algorithm allows one to obtain a good-quality skeleton of the objects in the color image. However, employment of the harmonic functions decelerates the process of the preparation of the image for processing, therefore, subsequent refinement of the algorithm through the optimization of the coordinate transformation is possible.

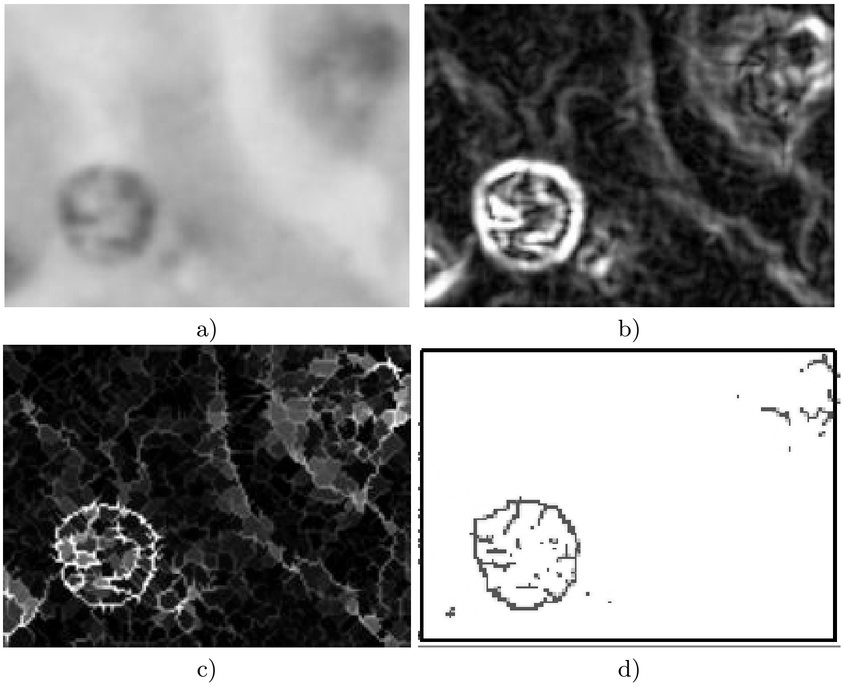

Fig. 3. The process of separation of the nucleus of the cell from a histological image: (a) initial image; (b) Sobel gradient transformation with respect to the radius-vector of the color distance; (c) thinning with respect to the radius-vector of the color distance; (d) threshold segmentation with respect to the hue and binarization.

6 Comparisons

Let us compare thinning in the proposed coordinate system with that in other systems. The result of the processing of pseudoimages, which consist of the vectors L and S of HLS system, is presented in Fig. 4a. There are many superfluous ridges in this system, although processing here may be accepted as satisfactory.

Systems MKO with adapted to human vision monochromatic luminance Y (YUV, YXZ, YIQ, etc.) are also well accepted. Thinning is not very effective in these systems because they do not take into account correlation between the luminance and saturation. The result of the processing of pseudoimages, which consist of vectors Y of YIQ system is presented in Fig. 4c. In this coordinate system, there is a distortion of colors. Similar operations in the RGB system lead to occurrence of false branches, ridge bifurcation, distortion of the geometric colorimetric properties (Fig. 4b) and do not lead to a result of practical significance.

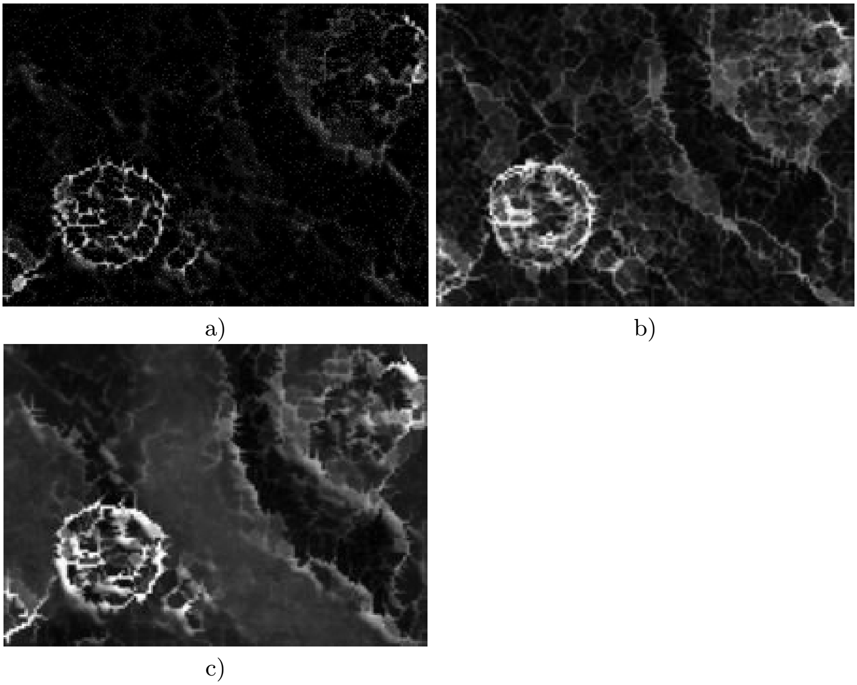

Fig. 4. The results of image thinning for extraction of a cell nucleus in hystology image: (a) in HLS system; (b) in RGB system; (c) in YIQ system.

7 Conclusion

Algorithm for thinning of color images has been proposed. Special color coordinate system PHS has been proposed that allows to take into account specifics of images and algorithm. The proposed algorithm was tested on the biomedical images. Comparison with other coordinate color system was given that shows the image thinning in PHS system produces a rather high-quality skeleton of objects in a color image.

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