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Color balloon snakes for face segmentation

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ABSTRACT

In this paper, a new color balloon snake model is introduced and used for face segmentation in color images. It is an extension of existing balloon snake models. Based on a coarse detection of facial features, the method combines a skin-tone distribution model and a boundary diffusion model to search for the facial boundary. The skin distribution is a single Gaussian, which is proposed to extract the skin-tone region in the RGB space. The diffusion model, which is invented to diffuse the facial boundary, is a one-dimensional Gauss revolution surface. The parameters are evaluated based on an AdaBoost face detection method. The color snakes are weighted by the distributions, and the external forces evolve dynamically to reach the boundary, which depends on the balance between the internal and external forces. Experiments were conducted, and the results show that the model provides desired segmentation outcomes. It is robust against complex backgrounds and lighting pollution.

1. Introduction

Image segmentation is the crucial problem in image analysis and image understanding. The face segmentation is a significant initial step for face reconstruction and recognition. It is also an important problem of computer vision and pattern recognition for the reason that it widely used not only in face recognition but also in other areas like pedestrian detection. Active contour model (ACM) is one of the most successful techniques in image segmentation. However, it is seldom applied to face segmentation, furthermore, ACM cannot be applied directly to color images because of the vector nature. Since color images contain more information than gray images, the segmentation of color images should be implemented in the color space rather than in the gray space. Unfortunately, in computer vision applications based on color-segmentation there is a common problem: the sensitivity to changes in the light intensity. In this work a color balloon snake model is presented to employ color information and alleviate lighting influence.

The classical snake approach [1] is based on deforming an initial curve toward the boundary of the object to be detected. However, the snakes are sensitive to the initialization, and the initial curve must be near the boundary. A balloon model [2] was proposed to extend the attraction of external forces. The balloon forces, which are irrelevant for the image data, are inward, unit normal vectors of the snakes. The external forces are composed of the balloon and potential forces. The initialization should be inside or outside the boundary. The gradient vector flow (GVF) field model [3] diffuses the initialization further, and the initialization can be inside, outside, or intersecting the object's boundary. However, they cannot directly work in the color space. A color snake model was proposed in [4] for boundary detection in vector-valued images. Unfortunately, the model is inadequate for complex background.

In order to achieve better segmentation result, many interactive methods have been proposed [5,6], which require the user to define the desired object to be extracted in advance.

There are also some literatures specially embedded in face segmentation. Traditionally, face segmentation aims to extract face region based on color and shape information [7]. Recently, segmentation usually consists of two stages, i.e., desired object detection and object extraction. Li et al. [8] employed AdaBoost learning algorithm to detect face and graph cut optimization method to segment the face. Luu et al. [9] proposed a modified GrowCut approach named FaceCut to accomplish face segmentation. In [10], a modified level set evolution equation, which is implemented in the gray space, is used in the level set method to segment the face.

In this paper, color balloon snakes are presented for face segmentation. A weighted color snake model for face segmentation is designed by combining the coarse detections. In Section 2, the classical balloon model is introduced. The color snakes are presented in Section 3. Contrastive experiments are presented and discussed in Section 4 and the concluding remarks follow in Section 5.

2. Balloon snake

Let the deformable contour model be represented by $X(s) = (x(s), y(s))$, where $s \in [0, 1]$ is the parameter and x and y are the

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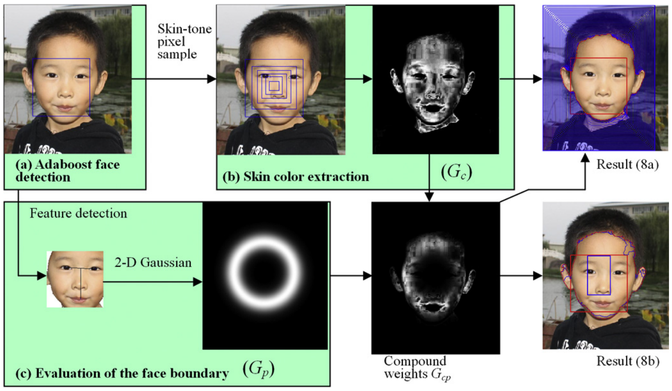

Fig. 1. The framework of the face segmentation algorithm.

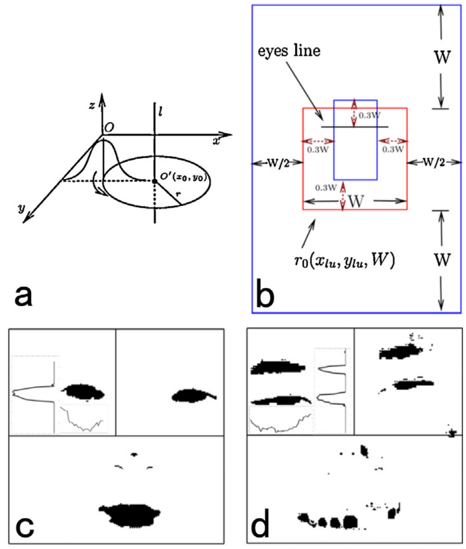

Fig. 2. (a) The Gaussian revolution surface. $O'(x_0, y_0)$ is the midpoint of the two detected eyes, r is the rotating radius. (b) The initialization of snakes. The red square is the face region detected by AdaBoost face detection method. The blue rectangles are the initializations. (c) and (d) The detection of the eyes and mouth. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

coordinates of the image plane. Generally, a snake is the curve $X(s)$ that minimize the energy functional [3]

$$E = \int_0^1 \frac{1}{2}\left[\alpha\left|\frac{\partial X}{\partial s}\right|^2 + \beta\left|\frac{\partial^2 X}{\partial s^2}\right|^2\right] + E_{ext}(X(s))\,ds, \tag{1}$$

where α and β are the parameters that control the tension and rigidity of the snake, respectively. $E_{ext}(X(s))$ is the external energy on the curve X. In the entire spatial domain, E_{ext} in Eq. (1) is usually represented as $E_{ext}^{(1)}(x, y) = -|\nabla I(x, y)|^2$, or $E_{ext}^{(2)}(x, y) = -|\nabla[G_\sigma(x, y) * I(x, y)]|^2$, where I is a given image, $I(x, y)$ is the pixel value at (x, y) of I, $G_\sigma(x, y)$ is a 2-D Gaussian function with a standard deviation σ, and ∇ is the gradient operator.

In order to minimize the energy functional in Eq. (1), the Euler–Lagrange equation can be built as follows [3]:

$$\frac{\partial X}{\partial t} = F_{int} + F_{ext}, \tag{2}$$

where the snake is appended to the dynamic time variable t to find the solution for convenience, and $F_{int} = \alpha X''(s, t) - \beta X''''(s, t)$, $F_{ext} = -\nabla E_{ext}$.

In order to improve the poor convergence condition, the balloon snakes [2] are determined by improving the external forces as follows:

$$F_{ext} = k_1 \vec{n}(X) - k_2 \frac{\nabla E_{ext}}{\|\nabla E_{ext}\|}, \tag{3}$$

where $\vec{n}(X)$ is the normal unitary balloon force applied to the curve $X(s, t)$, and k_1 and k_2 are chosen such that they are of the same order.

3. Color balloon snake

An overview of our face segmentation algorithm is depicted in Fig. 1, which contains four major modules: (1) face detection, (2) skin color extraction, (3) evaluation of the face boundary and (4) weighted snakes segmentation. The algorithm first estimates a coarse face location using AdaBoost face detection method [11]. Then, extracts skin color using an elliptical Gaussian distribution [12,13]. Third, a revolved Gaussian distribution covered face is presented to evaluate the face boundary. Finally, the extracted skin model and the evaluated boundary model are compounded to derive the adaptive weighted snake.

3.1. Skin color extraction

The snake model is based on the balance of the external and the internal forces. This method is sensitive to the properties of the image at the edges of the face, so the face region should be highlighted clearly. First, the coarse face position is determined using the AdaBoost face detection method [11]. The result (Fig. 1a) is noted as the square $r_0(x_{lu}, y_{lu}, W)$, where x_{lu}, y_{lu} are the indices of the left-upper corner, and W is the length of a side. Second, a skin distribution model is proposed to extract the face-tone region. Similarly to [12], pixels are classified as face pixels if: $R > G$, $R > B$, $R > 50$ and $max\{R, G, B\} - min\{R, G, B\} > 15$. Let I_{fp} be the set of color vectors that satisfy the aforementioned conditions. Determining whether a pixel at (x, y), noted $p(x, y)$, with intensity $I(x, y)$ is a face color pixel is a fuzzy problem. This can be modeled by a Gaussian joint probability density function (PDF) [13],

$$\mu_f(p(x, y)) = G(I(x, y)) = e^{-(1/2)(I(x,y)-\mu)^T \Sigma^{-1}(I(x,y)-\mu)}, \tag{4}$$

where μ and Σ are the distribution parameters. They are estimated by the pixels of $\{p(x, y)|(x, y) \in r_0, I(x, y) \in I_{fp}\}$. The samples are extracted by zooming r_0 out by margins wide of 10 pixels until the processing loses practical significance (Fig. 1b). The skin extraction model is proposed as follows,

$$G_c = \frac{G(I(x, y))}{\sup\limits_{p(x,y)\in I} G(I(x, y))}. \tag{5}$$

3.2. Evaluation of the face boundary

The model of the face boundary evaluation is proposed to diffuse the facial boundary. It is created by rotating a one-dimensional (1-D) Gaussian around a straight line (Fig. 2a) and is determined based on the center and size of the face. They are estimated using the position and proportion of the facial features. In this paper, the eyes and the mouth are used to build the distribution (Fig. 1c).

There are many techniques for facial feature detection, such as projection [14–16], Gabor wavelets [17,18], active appearance models [19,20], and Haar-like feature extraction methods, which are introduced in detail in [21]. In this paper, we apply the projection-like methods to extract the eyes and mouth. These methods can predigest the feature detection, and they do not need training processing. The algorithm is outlined as follows.