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Automatic extraction of face contours in images and videos

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ABSTRACT

The paper proposed an automatic and accurate extraction of the human face contour algorithm. Because a human face contour includes very important facial features to identifying or verifying a person, the accuracy of face contour extraction influences performance of face recognition. The automatic extraction human face contour algorithm includes a novel flowchart for improving accuracy of face contours extraction. To obtain the edge map of a face contour, the divided-and-conquer technique and Canny edge detector were used to avoid the features in the central part of face. The genetic algorithm is implemented to automatically find the parameters of Canny edge detector. Finally, the Poisson gradient vector flow (PGVF) active contour model used the edge map to extract face contours. Three datasets with temporal sequence images were tested for evaluation of the proposed algorithm. The experimental results demonstrated that the algorithm obtained accurate face contours.

1. Introduction

Face detection and recognition are techniques that are widely used in the world. Smart cameras can track, zoom, auto-focus, or auto crop on faces. Isolating faces for special purpose image and video enhancement can be achieved by image and video processing. Face centric compression applying compression at a higher bit rate on faces. Red-eye removal and face synthesis onto a digital avatar or modifying faces for entertainment purposes are very interesting applications of face detection. Transit systems are commercial applications using face detection for counting the number of people who pass in front of a camera. Interactive products use face detection or recognition to make products more interactive such as video games or face-aware toys that are toys that recognize their owners. Assistive devices use face recognition to assist the disabled persons who are patients having visual impairment, Prosopagnosia (face blindness) or Alzheimer's disease. Verifying ID using face recognition is an additional layer of security for verifying identity in combination with passwords, documents, or other biometrics.

Face detection is a computer technology that determines the locations and sizes of human faces in images or videos. Face recognition is another computer technology for automatically identifying or verifying a person from a digital image or a video frame from a video source by comparing selected facial features. The accuracy of face detection influences performance of face recognition. To detect locations and sizes of human faces in images or videos is not enough for the facial recognition system. The exact face contour includes very important facial features to identifying or verifying a person. The purpose of the paper is to develop a new algorithm to exact accurate face contours.

Bledsoe [1,2] was a pioneer to develop a face classification system cooperating the manual effort and software computing in 1966. In this study, some mark points such as eye corner, mouth corner, nose tip, and chin point are made by hands. The ratio of normalized distances between these points was computed for face classification. Fischler and Elschlager [3] extended dynamic programming (DP) and developed the linear embedding algorithm (LEA) to measure the fitness of matching or detection. Template matching [4–7] was used to approach the face detection problem in the period between 1989 and 1993 and Pentland et al. [8] used a large face database to test the eigenfaces technique. Yang and Waibel [9] proposed a real-time face tracking algorithm which was based on skin color information in 1995. Besides template matching and skin color information were used to detect faces in images, statistical, clustering and neural network methods [10–12] are also widely used for face detection. Face shape is another important feature for face detection and tracking. Birchfield used a two-dimensional model, namely an ellipse, to

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approximate the head's contour [13]. However, an ellipse is only an approximate contour of a human head. Gunn and Nixon [14–16] used classical active contour model to extract head boundary and face contour in gray images. Sobbotka and Pitas [17,18] used classical active contour model for face contour extraction in color image in 1998. According to the above researches, active contours or snakes were proved efficient methods in face contour detection and tracking. But the drawbacks of active contours are very sensitive to initial positions and the position of the contour might converge to local minima. Perlibakas [19] used generalized gradient vector flow (GGVF) active contour model [20,21] for face contour extraction. Because the edge maps of GGVF included face features (eyes, lips and mouth), he used the Canny edge detector [22] to find a mask to remove edges in the central part of a face for pushing snake away from them. The approach cannot accurately extract the contours of faces because the shape of the mask is not good enough to remove all edges of eyes, lips and the mouth. Although the active contour models were widely applied on several other fields, such as cellular images [23,24], MR functional cardiac images [25] and virtual reality in medicine and biology [26], but all the active contour models mentioned above are not good enough to solve the problem of face contour extraction. In this paper, we proposed a new approach to avoid finding all edges of a human head, but only the edges of the face contour. The divided-and-conquer technique is applied to solve the problem of face contour extraction. Four parts divided from an image, chin, forehead, right face and left face, need separate parameters of Canny edge detector to find the contour of a head in this part. However, three parameters including two thresholds and a sigma of Canny edge detector are selected depending on each part of images. It is time consuming manually to select these parameters of Canny edge detector for discarding face features. In this paper, our previous work PGVF active contour model [27,28] is used to detect the face contours. The edge maps of PGVF active contour model can be directly obtained by Canny edge detector with divided-and-conquer technique. Genetic algorithms (GAs) are used to automatically select the optimal parameters of Canny edge detector by evaluating fitness functions. GAs are inspired by Darwin's theory about evolution. GAs published in the Holland's book "Adaption in Natural and Artificial Systems" were invented by [29,30] and developed by him and his students and colleagues. For completeness of the paper, there is brief review of PGVF active contour model, Canny edge detector and GA in the second section.

2. Mathematical theories

Active contour model, Canny edge detector and GA are methods widely used in image processing application. It is important to know how these methods works to understand the new developed face contour extraction algorithm.

2.1. PGVF active contour model

The PGVF active contour model is proposed in our previous paper [27,28] to improve the drawbacks of the classic active contour model and GVF ACM model. One drawback of the traditional method cannot catch the boundary in the concave shape. The GVF and PGVF methods conquer the drawbacks, but the GVF method has the stability condition problem. There are differences between PGVF and GVF schemes to construct the image force fields. The GVF method considers the time variable and it has the instability condition of the initial value problem. The PGVF method by solving Poisson equations considers a boundary value problem and it does not suffer the stability problem as GVF. The theory of PGVF is briefly introduced for the completeness. The active contour model describes parametric curves with continuous points. These points are represented by position vector $\vec{X}(s) = (x(s), y(s))$ which is a function of the length parameter s in the interval [0, 1]. The total energy of an active contour involves internal energy and external energy and can be expressed as a functional E as follows:

$$E = \int_0^1 \left\{ \frac{1}{2} \left[\alpha \left| \frac{\mathrm{d}\vec{X}}{\mathrm{d}s} \right|^2 + \beta \left| \frac{\mathrm{d}^2\vec{X}}{\mathrm{d}^2 s} \right|^2 \right] + E_{\mathrm{ext}}(s) \right\} \mathrm{d}s. \tag{1}$$

where external energy $E_{\mathrm{ext}}(s)$ is generated by the external forces applied on an active contour. There are two approaches to obtain the optimal solution $\vec{X}(s)$. One is using some optimization procedure to minimize the energy of the functional E. The other approach is using the calculus of variation theory to obtain the Euler Lagrange equations [31]. Using calculus of variation and Eq. (1), we obtained the Euler equations:

$$\alpha x_{ss} + \beta x_{ssss} + F_x = 0 \tag{2}$$

and

$$\alpha y_{ss} + \beta y_{ssss} + F_y = 0 \tag{3}$$

where the variation calculus of $E_{\mathrm{ext}}(s)$ generated by external image force field has two components F_x and F_y; x_{ss} and y_{ss} are the second derivatives, x_{ssss} and y_{ssss} are the fourth derivatives of x and y coordinates with respect to the independent variable s. Eqs. (2) and (3) can be written in the matrix form after discretization the Euler equations. The solution of the discrete system equations is iterated until fixed coordinates are found for each sample point in the discretized contour [32]. The two components of external image force field are computed by $F_x = -\frac{\partial \phi}{\partial x}$ and $F_y = -\frac{\partial \phi}{\partial y}$, where the function ϕ is a solution of the Poisson equation as follows:

$$\nabla^2 \phi(x, y) = f_{\mathrm{edge}}(x, y). \tag{4}$$

The function $f_{\mathrm{edge}}(x, y)$ is a binary image obtained by the Canny edge detector applied on original gray images. The continuous function $\phi(x, y)$ of the Poisson equation can be solved by the finite difference method. To approximate the continuous function $\phi(x, y)$ with a discrete function $\phi(x_i, y_j)$ by using Taylor expansions expanded about the index point (ih, jh) where (x_i, y_j) is the location of the (i, j) the pixel in an image and $x_i = ih, y_j = jh$. Considering a square domain $0 \le x, y \le L$ with the boundary conditions $\phi = 0$ and the square domain is discretized into $(N + 2) \times (N + 2)$ grid points. Every rows and columns of the grid points have N interior points and two boundary points in both the $\boldsymbol{x}$ and $\boldsymbol{y}$ directions. Using the finite difference numerical method to discretize the two-dimensional Poisson equation, the finite difference formulation of Eq. (4) is as follows:

$$\phi_{i,j} = \frac{1}{4}(\phi_{i+1,j} + \phi_{i-1,j} + \phi_{i,j+1} + \phi_{i,j-1} - h^2 f_{i,j}). \tag{5}$$

The boundary value problem will result in an linear system $[A]\{\phi\} = \{b\}$. Because the matrix $[A]$ is block tridiagonal and sparse, there are many methods, a generalized Thomas algorithm, cyclic reduction, successive overrelaxation, and Fourier transforms, developed to optimally solve this linear system for solution $\{\phi\}$. Multigrid methods has theoretically optimal computation complexity $O(n)$ to compute solution of the linear system.

2.2. Canny edge detector

The Canny edge detector is an edge detection method to look for important edge in a gray image. The Gaussian smoothing filter as a convolution operation with standard deviation σ is applied on the grayscale image to reduce noise. The gradient of the smooth grayscale image is used to find a normal vector perpendicular to