A FLEXIBLE ARCHITECTURE FOR FEATURE-BASED IMAGE EDITING

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ABSTRACT

This paper presents a scheme for feature-based image editing. In the proposed method, an image is decomposed into a skeleton component and a residual component. The skeleton component is obtained by performing iterative linear interpolation based on high-curvature points, which are extracted from the image surface using Hessian tensor. The residual component is obtained by subtracting the skeleton component from the original image. By manipulating the skeleton component and the residual component, several applications, such as adaptive contrast enhancement, sharpness enhancement, and shape editing, can be achieved. Experimental results are provided to verify the versatility and flexibility of this proposed architecture.

1. INTRODUCTION

A benefit of digital imaging lies on the property that the content of an image can be edited into a more "suitable form" based on various task requirements. To edit or enhance an image, several methods have been proposed [1]-[6]. For example, in [2], a sketch editing framework is proposed to decompose a handwritten figure into visual structures for ease of manipulation. In [3], an optimal path between two points assigned by users is calculated using dynamic programming. In [4], to enhance an image, a new adaptive contrast enhancement algorithm is proposed to reduce noise over-enhancement and ringing artifacts. In [6], an edge-based method with parameters is proposed to edit an image. The term "suitable form", however, is quite subjective. It is difficult to have a single and universal criterion for "suitability" that holds for various types of applications. For instance, for a blurred image, we might aim at the enhancement of sharpness; while for an image lack of observable details, we might aim at the enhancement of contrast. Moreover, if we are interested in specific features, like the intensity or shape of an object, only a portion of the image needs to be amended while the rest part of the image should remain unchanged.

Since it is difficult to anticipate in advance how an image should be modified, a flexible architecture for image editing is needed. In this paper, based on the image representation scheme proposed in [8], we developed a flexible architecture featured in three aspects. First, an image is decomposed into the skeleton component and the residual component. By tuning different weightings of these two components, different effects could be manifested. Second, unlike the pixel-based scheme used in traditional image editing software, we extract the features in an image and perform feature-based editing. Third, to allow a more convenient way to edit the shapes of objects in an image, we approximated the shapes using B-spline curves. The rest of this paper is organized as follows. In Section II, we present the concept of image editing. In Section III and IV, we demonstrate image editing in intensity domain and shape domain, respectively. In Section V, we conclude this paper.

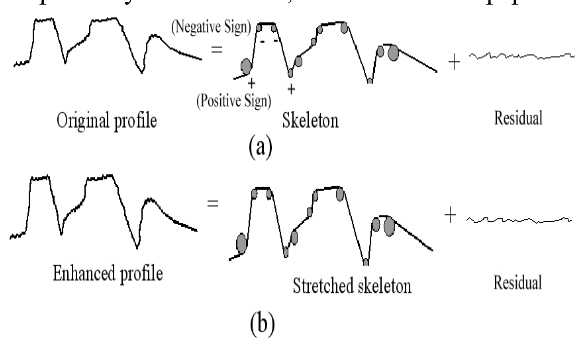

Fig. 1. Concept of image decomposition. High curvature points are indicated by gray circles.

2. CONCEPT OF IMAGE DECOMPOSITION

Let D indicate the domain of an image in the two-dimensional (x, y) plane

$$D=\{(x,y)|\ 1\le x\le x_{max},\ 1\le y\le y_{max}\}, \quad (1)$$

and f(x,y) indicate the intensity value of the pixel at (x,y). Then, the image can be expressed as

$$F(D) = \sum\sum_{(\mu,\eta)\in D} f(\mu,\eta)\delta(x-\mu, y-\eta), \quad (2)$$

where δ indicates the 2-D Dirac impulse function. In this paper, we intend to divide the image F(D) into a skeleton component and a residual component; that is

$$F(D) = F_{skeleton}(D) + F_{residual}(D). \quad (3)$$

We first illustrate the concept of the proposed approach using a one-dimensional image profile. To obtain the skeleton component of a profile, we find the high curvature points in the profile, and then apply linear interpolation over these high curvature points. As shown in Fig. 1(a), the interpolated profile does catch the outline of the original profile. Hence, we name the high curvature points and the interpolated profile as skeleton points and skeleton component. After having obtained the skeleton component, the residual component is defined as the difference between the original profile and the skeleton component. The residual component represents the properties of the profile, such as coarseness or smoothness. This decomposition allows us to control the skeleton component and the residual component separately. For example, we may intend to increase the contrast between a human face and the background without enhancing texture of the face. This goal can be achieved by moving up and down the skeleton points to stretch the contrast of the skeleton component, while keeping the residual component unchanged (see Fig. 1(b)). Similarly, a softened image can be obtained by reducing the contrast of the skeleton component. The image sharpness can be improved by moving skeleton pairs (two skeleton points with different signs) toward each other. In addition, by adjusting the amount of the residual component, different visual effects, such as "smoother" or "coarser", can be obtained. Furthermore, since skeleton points divide the profile into several segments, changing the position of a skeleton point would only influence adjacent segments. This allows local controls of the image contents.

This concept in one-dimensional profiles can be extended to two-dimensional images. Here, an image is considered as a three-dimensional image surface (x,y,f(x,y)). We use the Hessian **H** in differential geometry [7]

$$\mathbf{H}=\begin{bmatrix} f_{xx} & f_{xy} \\ f_{xy} & f_{yy} \end{bmatrix}=\begin{bmatrix} \dfrac{\partial^2 f(x,y)}{\partial x^2} & \dfrac{\partial^2 f(x,y)}{\partial x \partial y} \\ \dfrac{\partial^2 f(x,y)}{\partial x \partial y} & \dfrac{\partial^2 f(x,y)}{\partial y^2} \end{bmatrix} \tag{4}$$

to extract skeleton points [8]. The eigenvalues $k_1(x,y)$ and $k_2(x,y)$, with $|k_1(x,y)| \ge |k_2(x,y)|$, represent the principal curvatures at (x,y). To obtain the skeleton points of an image f(x,y), we check for each pixel the magnitude of $|k_1(x,y)|$ and pick up these places whose $|k_1(x,y)|$ is larger than a predefined threshold T_k. The curvature threshold used in the extraction of skeleton points can be used to determine how many details should be captured in the skeleton component. Fig. 2(b) shows the extracted skeleton points of the image in Fig. 2(a), where positive skeleton points are indicated in red while negative skeleton points are indicated in green.

Assume the set of the positions of extracted skeleton points is expressed as Ω; that is,

$$\Omega=\{(x_{sp},y_{sp})\,|\,(x_{sp},y_{sp})\in \text{skeleton points}\}. \tag{5}$$

Once these skeleton points are given, the skeleton component $F_{skeleton}(D)$ can be generated using interpolation techniques [8], that is,

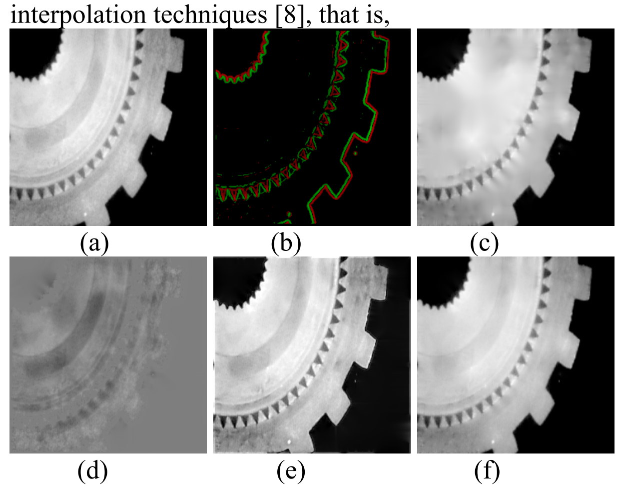

Fig. 2. (a) Original image. (b) Extracted skeleton points. (c) Skeleton component with threshold T_k = 6. (d) Residual component of Fig. 2(c). (e)Enhancing skeleton component only. (f) Changing residual component only; α is set as 0.5.

$$F_{skeleton}(\Omega;D) \equiv \Gamma\{\sum\sum_{(\mu,\eta)\in\Omega} f(\mu,\eta)\delta(x-\mu,y-\eta);D\}, \tag{6}$$

where $\Gamma\{\}$ denotes the interpolation process employed over the set of skeleton points to generate an image with domain D. Fig. 2(c) shows the skeleton component interpolated using the skeleton points in Fig. 2(b). Fig. 2(d) presents the residual component.

To adjust image contrast, we adopt two parameters, Δ_{sp} and α, in the following equation:

$$\begin{aligned}\widetilde{F}(D) = {} & \Gamma\{\sum\sum_{(\mu,\eta)\in\Omega}[f(\mu,\eta)+\Delta_{sp}(\mu,\eta)]\delta(x-\mu,y-\eta);D\} \\ & +\alpha\times F_{residual}(D).\end{aligned} \tag{7}$$

In (7), $\widetilde{F}(D)$ denotes the processed image. $\Delta_{sp}(\mu,\eta)$ indicates the amount of adjustment over the intensity value of a skeleton point at (μ,η). The parameter α indicates the proportion of residual component that is to be added into $\widetilde{F}(D)$. The sign of Δ_{sp} is determined by the sign of principal curvature at (μ,η), and the magnitude of Δ_{sp} can be either a constant or a function of $|k_1(\mu,\eta)|$. By choosing different α's and Δ_{sp}'s, different effects are manifested in the adjusted image $\widetilde{F}(D)$. For example, by setting α=1 and choosing a Δ_{sp} function to stretch skeleton points along the intensity axis, an image with enhanced skeleton and unchanged residual is obtained. As shown in Fig. 2(e), $\Delta_{sp}(\mu,\eta)$ is set as $2*k_1(\mu,\eta)$ and $\alpha = 1$. On the other hand, if we choose $\Delta_{sp}(\mu,\eta)=0$ for every skeleton point and set $\alpha<1$, an image with unchanged skeleton component but lighter texture (smoother surface) is obtained. By setting $\alpha>1$, on the contrary, produces an image with heavier residual component (coarser surface). In Fig. 2(f), $\Delta_{sp}(\mu,\eta)$ is set to be 0 and $\alpha = 0.5$. It can be seen that different types of contrast adjustment can be achieved under this proposed scheme.

3. EDITING IMAGES IN INTENSITY DOMAIN

The extracted skeleton points can be further linked into skeleton curves under the guidance of eigenvectors in **H** [8], which allows the users to adjust local features conveniently. The linked skeleton curves offer more information than skeleton points. Assume, after linking, M skeleton curves are extracted. Each skeleton curve is actually a subset of Ω. We denote these M skeleton curves as $\Psi_1, \Psi_2, \ldots, \Psi_M$. Now, for each skeleton curve, we may apply different manipulations. Hence, Equation (7) can be further modified into a curve-dependent form as expressed in (8).

$$\begin{aligned}\widetilde{F}(D) = \\ &\Gamma\{\{\sum_{i=1}^{M}[\sum\sum_{(\mu,\eta)\in\Psi_i}[f(\mu,\eta)+\Delta^i_{sp}(\mu,\eta)]\delta(x-\mu,y-\eta)]\};D\} \\ &+\alpha\times F_{residual}(D).\end{aligned} \quad (8)$$

Here, we denote $\Delta^i_{sp}(\mu,\eta)$ as the amount of adjustment over the intensity value of a skeleton point on the i^th curve. $\Delta^i_{sp}(\mu,\eta)$ may depend on the intensity at (μ, η), the average contrast of the i^th curve, and the length of the i^th curve. Since different processing may be needed for different features in an image, we can employ different strategies to satisfy different demands. For instance, if a user wants to enhance features with small contrast only, a threshold can be set over the curve contrast to pick up low-contrast curves. When a user hopes to highlight the objects with longer boundary, a large value of $\Delta^i_{sp}(\mu,\eta)$ can be applied over these curves with their curve length L longer than a pre-selected threshold. The proposed scheme provides a flexible scheme for various types of image enhancement methods. In comparison, it would be more troublesome to achieve this flexibility if we use some traditional image enhancement tools, like histogram equalization or the unsharp masking method. In Fig. 3, we show some examples of feature-based manipulations. Fig. 3(a) shows an original image. In this example, we set $\Delta^i_{sp}(\mu,\eta)$ as

(a) (b)

Fig. 3. (a) Original image. (b) Enhancing long features only.

(a) (b)

Fig. 4. (a) Original Image (b) Interactive editing.

(a) (b) (c)

Fig. 5. (a) Original image. (b) Example of feature removals. (c) Example of feature creations.

$$\Delta^i_{sp}(\mu,\eta) = \begin{cases} 0, & \text{if } L(i) < 20 \\ \sqrt{\dfrac{L(i)}{L_{\max}}}\times k_1(\mu,\eta), & \text{otherwise} \end{cases}, \quad (9)$$

where L(i) denotes the length of the i^th skeleton curve. The enhanced image based on (9) is shown in Fig. 3(b). It can be seen from this picture that features with longer boundaries are especially enhanced.

The concepts of these proposed methods are applicable to color images. To extract skeleton points from a color image, the original color image is first converted into an appropriate color space. Here, we choose the CIE LCH color space, which is relatively uniform and convenient, for adjustment. For a color image, we can change the altitude of skeleton curves to modify the brightness, hue, or saturation of the image. Fig. 4(a) shows a color image. In Fig. 4(b), we modify the hue component of some skeleton curves to change the chromatic information of the image content in the upperright corner. In comparison, it would be difficult to achieve this task using pixel-based processing or a block-based processing.

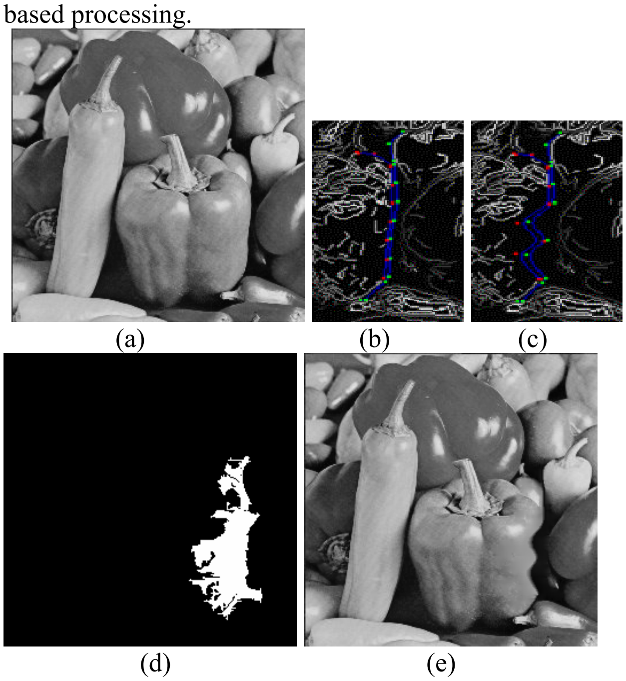

Fig. 6. Interactive shape editing. (a) Original image. (b) Original control points. (c) Modified control points. (d) Influenced zone. (e) Modified image.

4. EDITING IMAGES IN SHAPE DOMAIN

Since skeleton curves map to specific features of objects, shapes in an image could be edited by manipulating these skeleton curves. In Fig. 5(b), we show the removal of a window in Fig. 5(a) by eliminating the corresponding skeleton curves of the window. In Fig. 5(c), on the contrary, by adding some extra skeleton curves on Fig. 5(b), a new window is created.

To further strengthen the flexibility of the proposed architecture, the skeleton curves are approximated using B-spline curves with a set of control points. By shifting the positions of the control points in x-y plane, the shape of the selected object is changed. After this modification, however, the residual component cannot be added back directly since it does not match with the modified skeleton component. To solve this problem, we record for every pixel the supporting skeleton curves of that pixel. The supporting skeleton curves are defined as these skeleton curves that have ever participated in the linear interpolation process of this pixel. Once the shape of a curve is modified, all those pixels whose supporting skeleton curves contain this modified curve are marked as pixels of influence zone. The residual information in the influence zone is discarded in the reconstruction process to avoid mismatch in the modified image. The experimental results of shape editing are shown in Fig. 6. Fig. 6(a) shows an original image. In Fig. 6(b) and 6(c), the original control points and the modified control points are demonstrated. Fig. 6(d) presents the influence zones due to modification of some control points. Finally, in Fig. 6(e) the image with modified shape is shown. Compared with [6], the proposed method may provide wider flexibility in shape editing since the curves are approximated using B-spline representation. In addition, the rotation and scaling of an object approximated by B-spline curves are feasible due to the affined invariant property of B-spline curves.

5. CONCLUSIONS

This paper presents a flexible framework for image editing. An original image is decomposed into the skeleton component and the residual component. The skeleton component is constructed by skeleton curves, which consist of skeleton points obtained by using the concept of principal curvatures in differential geometry. By manipulating the skeleton component and residual component, contrast adjustment and sharpness enhancement can be achieved. Furthermore, to offer more flexibility, the skeleton points are linked into skeleton curves. By the aid of the skeleton curves, we can edit the features in an image adaptively. These skeleton curves are further approximated by B-spline curves. By changing the position of the control points, the shapes of objects in an image can be modified. Experimental results have shown the versatility and flexibility of the proposed scheme.

6. REFERENCES

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