CONTOUR COMPLETION OF PARTLY OCCLUDED OBJECTS FOR MORE NATURAL RASTER-VECTOR CONVERSION

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ABSTRACT

This paper proposes a system for completing the contour of an object which is partly occluded by other objects. The proposed system classifies objects into rotational symmetry objects, line symmetry objects and the other objects. To a rotational symmetry object, the system estimates the angle and center of rotation of the object focusing on the periodicity of the curvature change of the contour. Rotating the object with the estimated angle and center of rotation, the system reconstructs the occluded part of the contour. To a line symmetry object, the system detects line symmetry axes. The occluded part is completed by folding the shape to the line symmetry axes. To other shapes, the system uses a spline interpolation to complete the contour. We have experimentally confirmed the effectiveness and limitations of the proposed method by comparing the proposed method with human perception.

Index Terms— contour completion, amodal completion, symmetry shape, raster-vector conversion

1. INTRODUCTION

Increase use of vector image formats in various kinds of applications such as image editing, image retrieval, object recognition, games, CAD and map-based softwares, has generated great deal of interests in raster-vector conversion techniques and tools [1][2][3].

By converting a raster image into a vector image, objects are extracted from the image and individual objects can be edited. However, existing raster-vector conversion tools have a problem that they cannot correctly discriminate objects when the objects are overlapped. This is because these tools do not model human visual perception.

Fig. 1 shows an example of difference of object discrimination between humans and computers. To the image in Fig. 1(a), humans perceive a square and a triangle like Fig. 1(b). On the other hand, computers simply divide the image into the two parts like Fig. 1(c). Humans can estimate the occluded parts of objects based on the information of shapes, which is essential difference from computer's judgment that divides an image into regions based on physical lines.

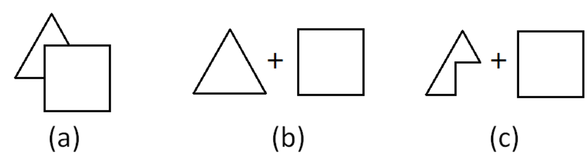

Fig. 1. Difference of object discrimination between humans and computers: (a) original image, (b) human perception, (c) computer's judgment

The human perception of completing object contours is known as amodal completion[4], and has been studied in the field of psychology[5][6][7]. These studies have experimentally revealed that local and global shape structures lead to amodal completion.

In order to make computers correctly discriminate objects in an images, this paper proposes a system for contour completion based on a model of amodal completion. The system completes object contours by considering rotational symmetry and line symmetry as global shape structures and the continuity of a contour as a local shape structure.

2. RELATED WORKS

Some studies regard the problem of contour completion as a problem of interpolation[8][9]. In these studies, using a parametric curve like a spline curve, the gap between the endpoints of the contour is interpolated. We call a completion by a curve *curve completion*. Generally, curve completion methods focus on the continuity of the contour, which is a local shape structure of an object. Curve completion methods have limitations that they cannot correctly complete object contours like Fig. 2(a) and (b), where (a) has multiple nondifferentiable points in the occluded part of the contour, and (b) is an occluded object whose contour cannot be estimated without considering the global shape structure.

A completion method considering a global shape structure has been proposed [10]. By the method, the hidden contour part of an rotational symmetry object can be completed. How-

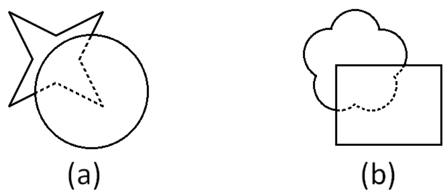

Fig. 2. Objects to which a curve completion fails

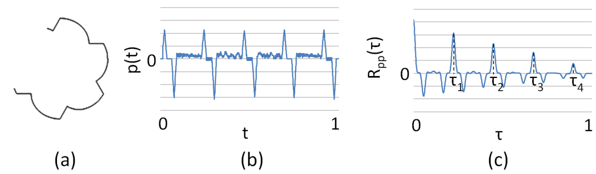

Fig. 3. The curvature and auto-correlation of an object. (a) input object, (b) the curvature ($p(t)$), (c) the auto-correlation ($R_{pp}(\tau)$)

ever, the method cannot be applied to other kinds of objects.

The proposed system in the paper combines completion methods considering local and global shape structures. As global shape structures the proposed system focuses on rotational symmetry and line symmetry structures, and as a local shape structure the method focuses on the continuity of a contour.

3. THE PROPOSED SYSTEM FOR CONTOUR COMPLETION

3.1. Outline

The proposed system uses three kinds of completion methods: (i) a method for completing the contours of rotational symmetry objects, (ii) a method for completing the contours of line symmetry objects and (iii) a method for completing the contours of other kinds of objects.

The input of the system is an image where a partly occluded object is drawn. When the system receives an image by a user, first the system judges whether the object has rotational symmetry. If the angle and center of rotation can be estimated to the object, the system restores the missing part of the contour by rotating the object and combining the rotated contour with the original contour. The details of the method are explained in Sec. 3.2. If the system cannot find proper parameters of rotational symmetry, next the system judges whether the object has line symmetry. If a line symmetry axis is detected to the object, the system completes the contour by folding the object to the line axis. The details of the method is explained in Sec. 3.3. If the object does not have either rotational symmetry or line symmetry, the system completes the contour with the interpolation by a spline curve.

3.2. Completion of a rotational symmetry object

The proposed system represents the contour of a partly occluded object as a parametric curve $\boldsymbol{r}(t) = (x(t), y(t))$ with parameter $t(0 \leq t \leq 1)$, where point $\boldsymbol{r}(0)$ and $\mathbf{r}(1)$ correspond with the start and end points of the contour, respectively. By using $\boldsymbol{r}(t)$, the curvature $p(t)$ is defined as

$$p(t) = \left| \frac{d^2 \boldsymbol{r}(t)}{dt^2} \right|. \tag{1}$$

$p(t)$ has periodicity if the original shape of the inputted object has rotational symmetry [10]. In order to judge whether the inputted object has rotational symmetry, the system estimates the periodicity of $p(t)$. To estimate it, the system calculates the auto-correlation $R_{pp}(\tau)$ to $p(t)$ as follows:

$$R_{pp}(\tau) = \int_0^1 p(t)p(t+\tau)dt. \tag{2}$$

When $R_{pp}(\tau)$ peaks at $\tau = \tau_i$, τ_i shows a period. Fig. 3 shows an example. In the figure, (a) shows an input object, (b) shows the curvature ($p(t)$) of the object and (c) shows the auto-correlation ($R_{pp}(\tau)$). As shown in the figure, at points $\tau = \tau_1, \tau_2, \tau_3, \tau_4$, $R_{pp}(\tau)$ peaks. The period τ_1, at which $R_{pp}(\tau)$ becomes maximum, is the basic period of $p(t)$, which means that period $\tau_k (k = 1, 2, 3, 4)$ can be calculated by $\tau_k = k\tau_1$.

From the periodicity of $p(t)$, next the system estimates the angle and center of rotaion as follows. First, from the information of the basic period τ_1, the system obtains the correspondences between points $\boldsymbol{r}(t)$ and $\boldsymbol{r}(t+\tau)$. Using the correspondences between points, the system estimates the angle of rotation $\theta(t)$ by

$$\theta(t) = \cos^{-1}\left(\frac{\boldsymbol{v}(t) \cdot \boldsymbol{v}(t+\tau_1)}{|\ \boldsymbol{v}(t)\ ||\ \boldsymbol{v}(t+\tau_1)\ |} \right), \tag{3}$$

where $\boldsymbol{v}(t)$ is the tangent vector at point $\boldsymbol{r}(t)$.

Here, using $\theta(t)$, the system discriminates rotational symmetry objects from others. In order to judge whether the inputted object has rotational symmetry or not, the system calculates the standard deviation of $\theta(t)$. If the inputted object has rotational symmetry, the standard deviation is close to 0. If the inputted object does not have rotational symmetry, the value becomes higher. Fig. 4 (a) and (b) shows the changes of $\theta(t)$ of two inputted objects. As shown in (a), to a rotational symmetry object, $\theta(t)$ little changes, which means the standard deviation of $\theta(t)$ is close to 0. On the other hand, as shown in (b), to a non-rotational symmetry object, $\theta(t)$ changes dynamically, which means that the standard deviation of $\theta(t)$ becomes higher. Therefore, rotational symmetry objects can be discriminated from others by using thresholding to the standard deviation of $\theta(t)$.

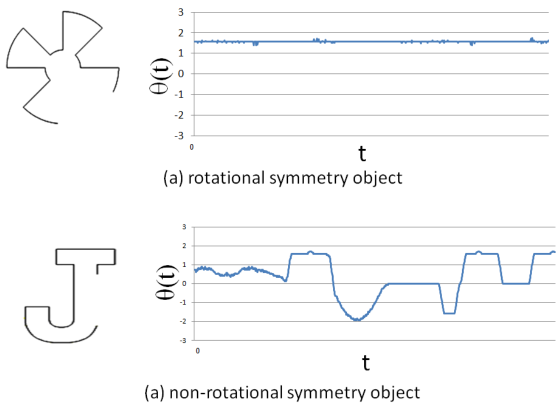

Fig. 4. Comparison of the angle of rotation $\theta(t)$ between a rotational symmetry object and a non-rotational symmetry object

The angle of rotation includes some errors because the actual coordinates of each point are digitized as integer values in the image. Therefore, the system calculates the average of the angles of rotations as $\bar{\theta} = \int_0^1 \theta(t)dt$. In addition, the system approximates the averaged angle $\bar{\theta}$ by $\hat{\theta} = 2\pi/n$ (2π, π, $2\pi/3$, $\pi/2$, etc.) as an estimation of angle of rotation $\hat{\theta}$.

Next, using the angle of rotation ($\hat{\theta}$) and the basic period (τ_1), the system estimates the center of rotation (x_c, y_c) by solving the following equation:

$$\begin{bmatrix} x(t+\tau_1) - x_c \\ y(t+\tau_1) - y_c \end{bmatrix} = \begin{bmatrix} \cos\hat{\theta} & -\sin\hat{\theta} \\ \sin\hat{\theta} & \cos\hat{\theta} \end{bmatrix} \begin{bmatrix} x(t) - x_c \\ y(t) - y_c \end{bmatrix}. \tag{4}$$

Finally, rotating the contour with the estimated parameters $\hat{\theta}$ and (x_c, y_c), and composing the rotated contour with the original contour, the system completes the hidden part of the contour of the object.

3.3. Completion of a line symmetry object

The system restores the hidden part of the contour of a line symmetry object by folding the contour to a line symmetry axis and overlapping the folded contour and the original contour. In the completion process, the computation of finding line symmetry axes is most important.

In order to find line symmetry axes of an object, the system focuses on a characteristic that $p(t)$ has symmetry at $t = t_i$, i.e., $p(t_i+t) = p(t_i-t)$ ($\equiv p(t) = p(2t_i-t)$) is satisfied. We call time t_i *a reflection time* of $p(t)$. At the point $\boldsymbol{r}(t_i)$, the contour of the object intersects with a line symmetry axis. Therefore, finding reflection times is the first step to detect line symmetry axes.

To find reflection times of $p(t)$, the system calculates the cross-correlation between $p(t)$ and $q(t) = p(1-t)$ as follows:

$$R_{pq}(\tau) = \int_{-1}^{1} p(t)q(t+\tau)dt. \tag{5}$$

$R_{pq}(\tau)$ peaks at delay time $\tau = \tau_i$ if $p(t)$ has symmetry at reflection time $t_i = (1-\tau_i)/2$. If such a reflection time is found, as mentioned above, the point $\boldsymbol{r}(t_i)$ in the contour is detected as an intersection point between the contour and a line symmetry axis.

However, to a partly occluded objects, not all the peaks of $R_{pq}(\tau)$ are corresponded with reflection times of $p(t)$. Fig. 5 shows an example. In the figure, (a) shows an input object, (b) shows the curvature ($p(t)$) and (c) shows the cross-correlation ($R_{pq}(\tau)$). As shown in (c), $R_{pq}(\tau)$ have five remarkable peaks A, B, C, D and E. In the these peaks, only peak D is corresponded with a reflection time of $p(t)$, and as shown in (a) only D is corresponded with an intersection point between the object contour and a line symmetry axis.

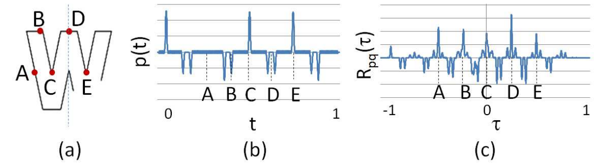

Fig. 5. The curvature and cross-correlation of an object: (a) input object, (b) the curvature ($p(t)$), (c) the cross-correlation ($R_{pq}(\tau)$) between $p(t)$ and $q(t) = p(1-t)$.

In order to detect line symmetry axes, the system checks whether each peak of $R_{pq}(\tau)$ is corresponded with an intersection point between the object contour and a line symmetry axis. For the check, the system assumes a line bisecting the contour at the point $\boldsymbol{r}((1-\tau_i)/2)$ as a candidate line symmetry axis. To the candidate line symmetry axis, the system folds the object contour to complete the contour, and checks whether the contour is closed. If the contour is closed, the system detects the candidate line symmetry axis as an actual line symmetry axis, and the result of completion is outputted.

4. EXPERIMENTAL RESULTS

We conducted an experiment to evaluate the effectiveness and limits of the proposed system. In the experiment, we compared completion by the proposed system to human perception.

Fig. 6 (a) shows 7 images used in the experiment and (b) shows inputted images to the proposed system. To the original images in (a), the results of amodal completion by human are shown in (c). To the inputted images in (b), the proposed system completed the contour as shown in (d).

As shown in Fig. 6, to No. 1 $\sim$ No. 5 images, the contour of the objects were correctly completed by the proposed

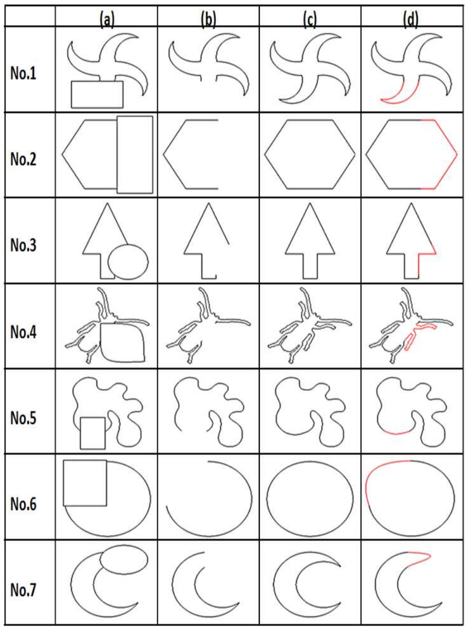

Fig. 6. Experimental results: (a) original image, (b) input image, (c) human perception, (d) completion by the system

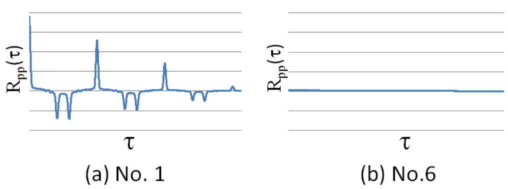

Fig. 7. The auto-correlations of No. 1 and No. 6 images

system. The results of No. 1 and No. 2 images were obtained by the method for completing rotational symmetry objects explained in Sec. 3.2. The results of No. 3 and No. 4 images were obtained by the method for completing line symmetry objects explained in Sec. 3.3. The results of No. 5 were obtained by the curve completion (spline interpolation).

No. 6 image was not correctly completed by the proposed system. No. 6 image has rotational symmetry and line symmetry. However, No. 6 image was not identified as either a rotational symmetry object or a line symmetry object. Fig. 7 compares the auto-correlation ($R_{pp}(\tau)$) of No. 1 image and the one of No. 6 image. As shown in (a), No. 1 image has several peaks and these peaks have periodicity. By the characteristics, No. 1 image was identified as a rotational symmetry object and the angle and center of rotation were correctly estimated. On the other hand, as shown in (b), $R_{pp}(\tau)$ of No. 6 has no remarkable peak. Therefore, the system cannot detect periodicity. The cross-correlation $R_{pq}(\tau)$ of No. 6 has the same problem. This is the reason why No. 6 was not identified as either a rotational symmetry object or a line symmetry object. To No. 6 image, the curve completion was applied. By the curve completion method, the contour was smoothly completed. However, the curvature of the completed contour was different from the contour completed by human.

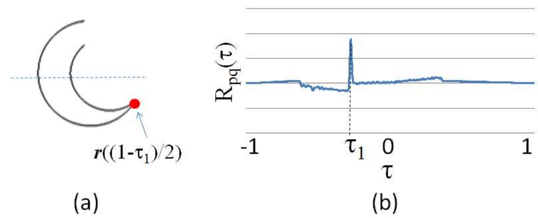

Fig. 8. The cross-correlation of No. 7 image

No. 7 image has line symmetry. However, the image was completed by the curve completion method like No. 6 image. That is, the image was not identified as line symmetry object. Fig. 8 shows the inputted image and the the cross-correlation $R_{pq}(\tau)$. As shwon in the figure, $R_{pq}(\tau)$ has one remarkable peak at $\tau = \tau_1$. However, the corresponding point $\boldsymbol{r}((1-\tau_1)/2)$ shown in (a) is not an intersection point between the contour and a line symmetry axis. Therefore, the system judged that the object has no line symmetry axis. As a result, the contour of the object was not correctly completed by curve completion.

To avoid mis-completion like No. 6 and 7, it is necessary to correctly distinguish object shapes. This is a problem to solve as a future work. Currently, to distinguish object shapes the proposed system focuses on the periodicity and reflection of the curvature $p(t)$. In addition to the information about curvature, the information of the coordinates $\boldsymbol{r}(t)$ would be useful to improve the discrimination of object shapes.

5. CONCLUSION

This paper has proposed a system for completing the contour of a partly occluded object focusing on rotational symmetry and line symmetry as global shape structures and continuity as a local shape structure. Experimental results have shown the effectiveness and limits of the proposed system. Improvement of the method for discrimination of object shapes remains as a future work.

6. ACKNOWLEDGMENT

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7. REFERENCES

[1] D. Dori and L. Wenyin, "From Raster to Vectors: Extracting Visual information from Line Drawings," Pattern Analysis and Applications, Vol. 2, No. 1, pp. 10-21, 1999.

[2] X. Hilaire and K. Tombre, "Robust and Accurate Vectorization of Line Drawings," IEEE Trans. Pattern Analysis and Machine Intelligence, Vol. 28, No. 6, pp. 890-904, 2006.

[3] V. Lacroix, "Raster-to-Vector Conversion: Problems and Tools Towards a Solution A Map Segmentation Application," Int. Conf. Advance in Pattern Recognition, pp. 318-321, 2009.

[4] G. Kanizsa, "Organization in Vision: Essays on Gestalt Perception, "Praeger Publishers, 1979.

[5] F. Boselie, "Local and Global Factors in Visual Occlusion, " Perception, Vol. 23, No. 5, pp. 517-528, 1994.

[6] A.B. Sekuler, "Local and Global Minima in Visual Completion: Effects of Symmetry and Orientation, ", Perception, Vol. 23, No. 5, pp.529-545, 1994.

[7] R. van Lier and P. van der Helm and E. Leeuwenberg, "Integrating Global and Local Aspects of Visual Occlusion," Perception, Vol. 23, No. 8, pp. 883-903, 1994.

[8] M. Teranishi and N. Ohnishi and N. Sugie, "Subjective Contours are Useful for Extracting Contours with Very Weak Contrasts, " Proc. Int. Conf. on Neural Network, Vol.1, pp. 139-142, 1993.

[9] Ben-Yosef and O. Ben-Shahar, "Minimum Length in the Tangent Bundle as a Model for Curve Completion, " Proc. IEEE Conf. Computer Vision and Pattern Recognition, pp. 2384-2391, 2010.

[10] M.V. Venkatesh and S.S. Cheung, "Symmetric Shape Completion under Severe Occlusions, " Proc. IEEE Int. Conf. Image Processing, pp. 709-712, 2006.