LI_015

Region Extraction with Cooperative Active Contours

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1. Introduction

The active contour (Snake, AC) [1] has been widely used for extracting object regions from images, because it can be applied to the various types of object regions by using appropriate energy functions, and user's intention can be reflected on extraction process by setting an initial contour.

For improving the region extraction accuracy with an AC, the methods applying multiple ACs to an image have been proposed [2, 3]. These methods make each AC extract a subregion of uniform image properties (e.g., colors, textures, etc.), and obtain the entire region of an object as a set of extracted subregions. This approach is effectual for complicated scene images, especially if the object region has uneven image properties (e.g., an object composed of various materials, illuminated unevenly, etc.). To enhance this effect, multiple ACs are applied not only to the target object region but also to the background, and made to compete among themselves. In this case, as shown in Fig. 1, a whole image is paved with multiple ACs and partitioned into subregions. However, unlike image segmentation, target region extraction requires only the boundary between the target region and the background, therefore partitioning of a whole image strays from the target region extraction and includes redundant processing.

To overcome this problem, a common goal, target region extraction, should be shared by all ACs, and ACs' processes should be integrated. For this purpose, we propose a cooperative active contour, which is an AC structured as an agent, and present a method for extracting a target region with multiple cooperative ACs. The proposed method applies multiple cooperative ACs to a target region and its background separately, makes them expand to the target region boundary, and determines the target region boundary as the borders between the ACs in the target region side and in the background side. Through the cooperation with others, each AC in one side controls its initial position and deformation direction so that its contour approaches the ACs in the other side rapidly. As a result, the proposed method can prevent redundant processing and reduce the processing time to determine the target region boundary.

2. Region extraction with multiple active contours

To improve the efficiency and the effectiveness in the target region extraction (i.e., boundary determination) with multiple ACs, several issues should be considered.

i. Position of initial contour

Every AC requires initial contours set by a user. These initial contours are not always set close to the target region boundary. If an initial contour is set away from the target region boundary, the AC needs many deformation steps and processing time to make it reach the target region boundary.

ii. Direction of contour deformation

Every AC deforms its own contour to extract a subregion of uniform image properties. However, deformation away from the target region boundary has little effect in determining the target region boundary, and consequently this type deformation is redundant.

iii. The number of contours

In determining the target region boundary, an appropriate number of ACs should be applied, because too many ACs increase the processing time and too few ACs decrease the extraction accuracy. However, it is difficult to determine the appropriate number of ACs in advance.

iv. Places bordering on more than two subregions

At a place bordering on more than two subregions, each subregion tends to form a corner. These corners are difficult to extract accurately with ACs, and they impede accurate determination of the target region boundary.

To resolve these issues, a common goal, target region extraction, should be shared by all ACs, and ACs should be made to cooperate among themselves for achieving the goal. For this purpose, a multiagent-based approach is suitable, and several methods have been proposed for image segmentation [4, 5]. However, those methods are designed for partitioning a whole image, and they are not effectual for extracting a user specified target region.

The above-mentioned issues are classified into two types: one is the problems of efficiency (i, ii, iii), and the other is the problems of effectiveness (iii, iv). By using ACs structured as agents, the method proposed in this paper aims to deal with the problems of efficiency (i, ii) in target region extraction.

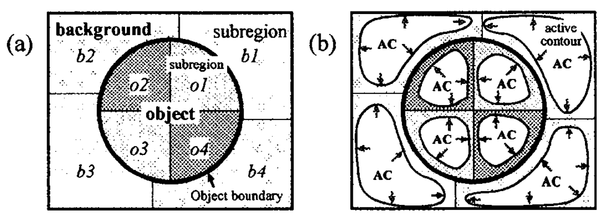

Fig. 1 Region extraction with multiple active contours.

3. Cooperative active contours

In the proposed method, a user sets initial curves in a target region and its background separately. Each initial curve is divided into segments, and initial contours are made from them. These initial contours are structured as agents and activated as cooperative ACs individually. The cooperative ACs estimate the user's intention of region extraction, and to determine the target region boundary efficiently, they control their initial positions and deformation directions through the cooperation among themselves.

3.1 Generating cooperative active contours

To achieve effective region extraction with multiple ACs, each initial contour should be set in a subregion of uniform image properties. In the proposed method, for every initial curve, the number of segments is given by the user, and by using the discriminant analysis method [6], an initial curve is divided into segments at the locations that minimize the total within-segment scatter of image properties (R, G, and B intensities). As shown in Fig. 2, an initial contour is made from each segment by shortening it at both

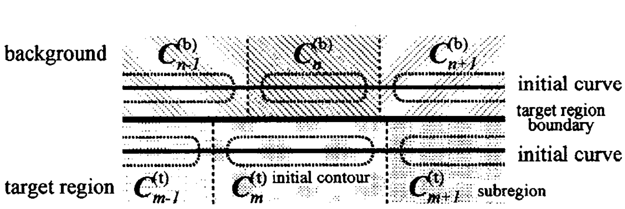

Fig. 2 Generating cooperative active contours.

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ends and dilating it to a definite width.

An agent is assigned to every initial contour. Each agent holds a set of nodes composing the contour, and has functions for exchanging messages with other agents and managing its own nodes. These agents are activated as cooperative ACs. In the following, cooperative ACs generated from the initial curves in the target region and the background are denoted by $C_m^{(t)}$ $(m = 1, 2, \ldots, M)$ and $C_n^{(b)}$ $(n = 1, 2, \ldots, N)$, where m and n represent the order of segments in each initial curve, and the centroids of $C_m^{(t)}$ and $C_n^{(b)}$ are denoted by $g_m^{(t)}$ and $g_n^{(b)}$, respectively.

3.2 Cooperation 1: Cooperation for contour shifting

To determine the target region boundary efficiently, cooperative ACs estimate the user's intention, and shift their own initial contours toward the target region boundary. In the target region, as shown in Fig. 3 (a), every $C_m^{(t)}$ sets the destination of contour shifting through the following cooperation (in the background, every $C_n^{(b)}$ also sets its destination similarly to $C_m^{(t)}$).

(1) Every $C_m^{(t)}$ sends $g_m^{(t)}$ as a message to all $C_n^{(b)}$.

(2) Each $C_n^{(b)}$ compares $g_n^{(b)}$ to the received messages, and sends $g_n^{(b)}$ as the response message to the nearest $C_m^{(t)}$.

(3) If $C_m^{(t)}$ receives the response messages, $C_m^{(t)}$ compares $g_m^{(t)}$ to the received messages, and it sets the destination at the nearest $g_n^{(b)}$ in the received messages. If $C_m^{(t)}$ receives no response messages, $C_m^{(t)}$ inquires of the adjacent ACs ($C_{m-1}^{(t)}$, $C_{m+1}^{(t)}$), and $C_m^{(t)}$ sets its destination at the nearer AC's one.

Each cooperative AC shifts toward its destination for S pixels, and then sets the destination again. The iteration of contour shifting in each AC stops when the scatter of image properties increases within its contour or the contour touches another contour.

3.3 Cooperation 2: Cooperation for contour deforming

Each cooperative AC controls the nodes of its own contour to minimize the energy $E = E_{\rm shp} + w_{\rm edg}E_{\rm edg} + w_{\rm sct}E_{\rm sct} + E_{\rm cp}$. The shape energy is defined as $E_{\rm shp} = \sum_k \alpha\|v'_k\| + \beta\|v''_k\| + \gamma(x_k y'_k - y_k x'_k)$, where a node of the contour is denoted by $v_k = (x_k, y_k)$, and the 1st and the 2nd derivations are denoted by $'$ and $''$, respectively. The edge energy is defined as $E_{\rm edg} = \sum_k \sum_{i={\rm R,G,B}} \|\nabla I_i(v_k)\|^2$, where I_i $(i = {\rm R, G, B})$ represent R, G, and B intensities. The scatter energy $E_{\rm sct}$ is defined by the scatter of $I_{\rm R}$, $I_{\rm G}$, and $I_{\rm B}$ within the contour. The cooperation energy is defined as $E_{\rm cp} = \sum_k w_{d1} d1(v_k) + w_{d2} d2(v_k)$, and determined through the cooperation among ACs. In these equations, $\alpha, \beta, \gamma, w_{\rm edg}, w_{\rm sct}, w_{d1}$, and w_{d2} are weighting factors.

To promote contour deformation effective in determining the target region boundary, in the target region, each $C_m^{(t)}$ expands to the adjacent cooperative ACs ($C_{m-1}^{(t)}$, $C_{m+1}^{(t)}$) through the minimization of $d1$ in $E_{\rm cp}$, and expands to the background through the minimization of $d2$.

- To determine $d1$ for $v_{m,k}^{(t)}$ of $C_m^{(t)}$ in the target region, every $C_m^{(t)}$ inquires $g_{m-1}^{(t)}$ and $g_{m+1}^{(t)}$ of the adjacent ACs, and classifies its own nodes $v_{m,k}^{(t)}$ into the $C_{m-1}^{(t)}$ side and the $C_{m+1}^{(t)}$ side by using the bisector of $\angle g_{m-1}^{(t)} g_m^{(t)} g_{m+1}^{(t)}$. For $v_{m,k}^{(t)}$ in the $C_{m-1}^{(t)}$ side, as shown in Fig. 3 (b), $C_m^{(t)}$ inquires of $C_{m-1}^{(t)}$ as to the distance between $v_{m,k}^{(t)}$ and the nearest node $v_{m-1,l}^{(t)}$ in $C_{m-1}^{(t)}$, and sets this distance to $d1(v_{m,k}^{(t)})$. Similarly, for $v_{m,k}^{(t)}$ in the $C_{m+1}^{(t)}$ side, $C_m^{(t)}$ inquires of $C_{m+1}^{(t)}$ and sets $d1(v_{m,k}^{(t)})$.
- To determine $d2$ for $v_{m,k}^{(t)}$ of $C_m^{(t)}$ in the target region, every $C_m^{(t)}$ makes perpendicular line outward from $v_{m,k}^{(t)}$, and as shown in Fig. 3 (c), $C_m^{(t)}$ inquires of other ACs whether this line intersects them or not, and determines the nearest crossing. If the nearest crossing is an intersection with an AC in the background, $C_m^{(t)}$ sets the distance between $v_{m,k}^{(t)}$ and this nearest crossing to $d2(v_{m,k}^{(t)})$. If the perpendicular line does not intersect any ACs or the nearest crossing is an intersection with an AC in the target region, $C_m^{(t)}$ sets a fixed value (default distance) $\tilde{d2}$ to $d2(v_{m,k}^{(t)})$.

In the background, every $C_n^{(b)}$ determines $d1$ and $d2$ similarly.

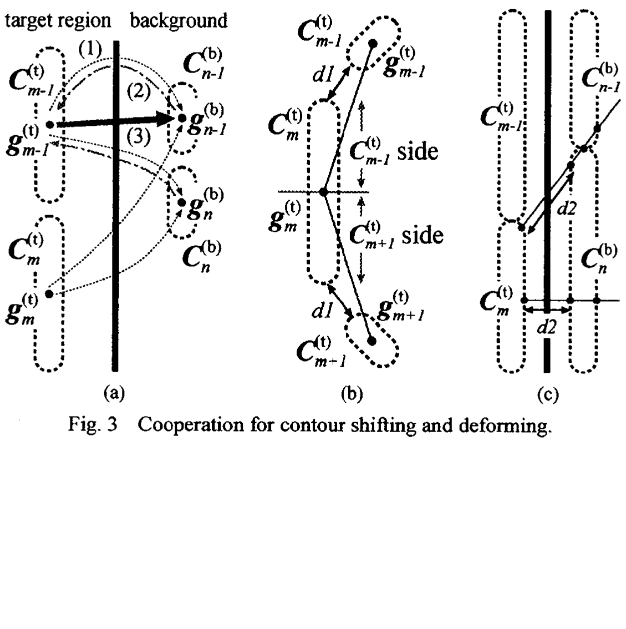

Fig. 3 Cooperation for contour shifting and deforming.

4. Target region extraction experiments

To confirm the effectiveness of the proposed method, we carried out target region extraction experiments on synthetic images.

4.1 Experimental environment

A prototype system was implemented on a PC (Pentium 4 3.2GHz, 1GB memory, Fedora Core 2), and the cooperative ACs were actualized as agents in DASH framework [7]. As shown in Fig. 4, each agent in the DASH framework consists of a communication module CM, knowledge module KM, action module AM, and base process BP [8]. To cooperate with other agents, an agent exchanges messages with others by using the CM, and to perform assigned tasks, the agent controls its own BP through the AM. The KM holds rule sets used for exchanging messages and controlling BP. In the prototype system, the BP is an active contour program implemented in Java, and it exchanges the state of its contour with other agents' BPs through the AM and CM.

To demonstrate the fundamental feature of the cooperative AC (the effect on the efficiency of target region extraction with multiple ACs), we used simple synthetic images in the experiments. Examples of image (Image 1 and 2) are shown in Fig. 5 and 6. Each image was 640 × 480 pixels in size and consisted of several subregions. The target regions in the Image 1 and 2 were the circular region composed of four subregions and the U-shaped region composed of ten subregions, respectively. Each initial curve set by a user was divided into the segments (the number of segments was given by the user), and each segment was shorten by

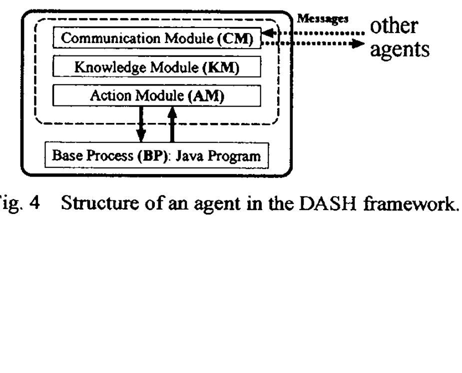

Fig. 4 Structure of an agent in the DASH framework.

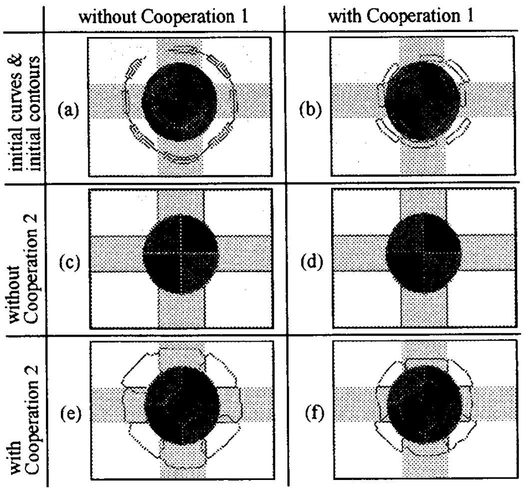

Fig. 5 Results of target region extraction (Image 1): (a) initial curves and initial contours, (b) initial contours shifted by the Cooperation 1, (c) extraction result without the Cooperation 1 and 2, (d) with 1 and without 2, (e) without 1 and with 2, (f) with 1 and 2.

20 pixels at both ends. Initial contours were made by dilating segments to 20 pixels in width. The shift unit in the Cooperation 1 was set as $S = 5$ pixels, and the default distance value for $d2$ in the Cooperation 2 was set as $\tilde{d2} = 5$ pixels. The weighting factors in E were set as $\alpha = 1$, $\beta = 2$, $\gamma = -3$, $w_{\text{edg}} = -5$, $w_{\text{sct}} = 1$, $w_{d1} = w_{d2} = 10$, respectively. Target region extraction finished when E converged at all cooperative ACs.

4.2 Experimental results

Experimental results of target region extraction (boundary determination) are shown in Fig. 5 and 6, and processing time and steps for the target region extractions are listed in Table. 1. In these figures, (a) shows initial curves set by the user and initial contours made from the initial curves, and (b) shows the initial contours shifted by the Cooperation 1.

In each figure, (c) is the target region extraction result without the Cooperation 1 (the cooperation for contour shifting) and the Cooperation 2 (the cooperation for contour deforming), and (d) is the result with the Cooperation 1 and without the Cooperation 2. Without the Cooperation 2, every subregion of uniform image properties was extracted entirely by a cooperative AC, and thus a whole image was paved with multiple ACs and partitioned into multiple subregions. In these cases, the Cooperation 1 could not improve the efficiency in target region extraction. Since initial contours were shifted to the boundaries of subregions by the Cooperation 1, the processing time and steps for extracting an entire subregion of uniform image properties were increased, and the efficiency in target region extraction was lowered.

In the figures, (e) shows the result without the Cooperation 1 and with the Cooperation 2, and (f) shows the result with the Cooperation 1 and 2. Compared to the results without the Cooperation 2, subregions extracted by the cooperative ACs were restricted to the neighborhood of the target region boundary, and then the processing time and steps for target region extraction could be decreased. Especially, by applying the Cooperation 2 with the Cooperation 1, the extracted subregions were restricted tightly to the neighborhood of the target region boundary, and the efficiency in target region extraction was considerably improved.

These experimental results illustrate that the cooperative ACs can improve the efficiency in target region extraction through the cooperation for contour shifting and deforming.

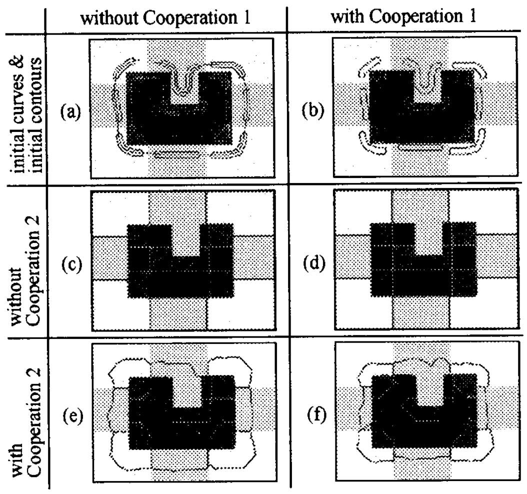

Fig. 6 Results of target region extraction (Image 2).

Table. 1 Processing time and steps for target region extraction.

Image 1

	without Cooperation 1	with Cooperation 1
without Cooperation 2	(c) 102s (150steps)	(d) 115s (175steps)
with Cooperation 2	(e) 66s (70steps)	(f) 51s (40steps)

Image 2

	without Cooperation 1	with Cooperation 1
without Cooperation 2	(c) 138s (93steps)	(d) 130s (124steps)
with Cooperation 2	(e) 126s (58steps)	(f) 81s (35steps)

5. Conclusion

In this paper, we have proposed the cooperative AC, which is an AC structured as an agent, and presented a region extraction method with multiple cooperative ACs. To determine the target region boundary efficiently, each cooperative AC controls its own initial position and deformation direction by the cooperation with other cooperative ACs. Through the experiments on synthetic images, we illustrated the effectiveness of the proposed method in improving the efficiency of target region extraction.

As mentioned in Section 2, the cooperation of multiple ACs is necessary not only to improve the efficiency but also to increase the effectiveness of target region extraction. In future work, we plan to investigate cooperation methods for improving the accuracy in target region extraction.

References

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