In the present contribution we describe an integrated technique of contour tracking based on motion compensation of salient points localized on edges, followed by a procedure of contour updating. Search of salient points is made by examination of the edge orientation in function of their curvilinear abscissa, and bifurcations are detected by colour variations.

1. Introduction

One of the fundamental issues of content analysis of video sequences is moving object detection and tracking. Object tracking is useful for many different tasks, including surveillance, vehicle velocity estimation, biometrics, scene indexing and retrieval, etc.

Conventional techniques for object tracking and recognition are mainly based on inter-frame differences, motion field analysis, template matching, etc. A distinct class of methods is based on tracking some specific features, such as salient points and contours. Salient point based object tracking is substantially aimed at improving robustness against disturbing factors such as illumination changes, scale and rotation, shape modification, out-of-plane rotation, etc. In fact, joint tracking of multiple isolated points allows to counteract the effects of geometrical changes, provided that such points are well recognized and localized (see for instance [5]). Contour tracking provides additional possibilities, such as dynamic segmentation and shape evolution detection and classification.

In the present contribution we describe an integrated technique of contour tracking based on motion compensation of salient points localized on edges, followed by a procedure of contour updating. The procedure constitutes an

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upgrade of the methods explored in [2] and [3], which takes also into account results of [1] and [4].

A problem associated to the contour tracking technique consists of properly breaking out single edge patterns pertaining to different objects. This is a central feature for higher level processing, where structural content analysis is performed. In essence, such a segmentation of edges requires detection of bifurcations (T patterns) occurring on contours when different objects overlap. Solutions to this problem based on differential operators are usually prone to false or missing detection. For this reason, we follow here a more robust approach based on comparison of colours aside edge trajectories.

Another problem consists of selecting salient points having the property of being unambiguously moto-compensated. Unlike the method followed in [3] where circular harmonic operators have been employed, here the evolution of the curvature along the contour trajectories is measured. Salient points are defined as isolated maxima of the curvature diagram in function of the curvilinear abscissa measured on each edge.

Such a set of salient points allows for contour moto-compensation using a technique similar to the watersheding described in [4]. In essence, contours are updated frame by frame by comparing edges passing on the moto-compensated points and using proper relaxation criteria. Some tricks for handling events such as edge occlusion and discovery, fusion and division are also employed.

2. Salient points detection method

The content analysis of the image starts with the extraction of edge contours. This is done by applying smoothed complex gradient operator constituted by a zero-radial first-angular order Gauss Laguerre Circular Harmonic Function (GL-CHF), whose expression in polar coordinates for radial order \( k=0 \) and angular order \( n \) is:

\[
g^{n,0}_s(r, \theta) = \frac{(-1)^{n}}{\pi} \frac{1}{s^2} \left( \frac{r}{s} \right)^n e^{\frac{i}{2} \sqrt{n(n+1)}} e^{-i \theta} \tag{1}
\]

where \( s \) is a scaling factor. These operators, which are obtained by complex differentiation of the Gaussian kernel, are polar separable and give complex outputs tuned to specific n-fold symmetric patterns. In particular, first-angular order operators are tuned to edges, whose strength is measured by the magnitude and orientation angle by phase. We apply this operator to each colour layer, and, in order to capture every gradient maximum irrespective of its colour, a unique multispectral complex gradient image is formed in a non-linear way by selecting in each point of the image support the complex edge value having the largest magnitude. Complex Multispectral Edges (CME) are then extracted by selecting in the multispectral complex gradient image the largest magnitude points pertaining to the trajectories of the Laplacian zero-crossing.
The second step of our procedure is aimed to break out contours pertaining to different objects. Preliminary, we select possible terminal salient points looking for the local maxima of the Euclidean Distance between the magnitudes of the first-angular order GL-CHF components calculated on two consecutive points of the generic edge. Thus, indicating shortly with $W^R_i$, $W^G_i$, $W^B_i$ the complex edge values for the three colour channels R, G and B along each contour at the $i$-th position, we calculate the maxima of the following quantity:

$$DE_w = \sqrt{(|W^R_i| - |W^R_{i+1}|)^2 + (|W^G_i| - |W^G_{i+1}|)^2 + (|W^B_i| - |W^B_{i+1}|)^2}$$ (2)

This detector is not sufficiently robust for our purpose. So, in order to confirm the presence of a bifurcation we pass to a second decision stage, where we verify the occurrence of local maxima of the Euclidean Distance between consecutive colour values, say $R_i$, $G_i$ and $B_i$, on both sides of the CME, taken in the original image:

$$DE_{st,de} = \sqrt{(R_i - R_{i+1})^2 + (G_i - G_{i+1})^2 + (B_i - B_{i+1})^2}$$ (3)

If a local maximum occurs at least on one side of a contour, then a break point is marked and labelled as a terminal point. In order to limit the number of detected salient points for each contour, an adaptive threshold is applied.

An example of result of this CME based contour segmentation technique is shown in fig. 1.

![Image](image.jpg)

**Figure 1.** Example of terminal salient points detection.

The subsequent step consists of locating along each contour salient points, defined as the ones having largest curvature. Instead of using conventional geometric techniques based on search of vertices of edge trajectories we extract here local orientations by means of the phase of the CME. Consider that the CME is based on smoothed operators, whose smoothing effect is easily regulated with the scale parameter $s$. In particular, we detect salient points as those
corresponding to abrupt and strong phase changes. An example is shown in fig. 2 where the phase diagram calculated along the contour just above the head clearly indicates the occurrence of a vertex as salient point.

An example of result of this CME based salient point extraction is shown in fig. 3.

![Figure 2](image)

**Figure 2.** Diagram of the phase values along a generic contour in presence of a corner point.
3. Object tracking

In essence, the present approach is based on detection of contours on single frames of a sequence and search of correspondences between frames. To do that, we adopt here the strategy of linking contours by means of selected points whose correspondence is reliably established. Salient points do possess such a property. Once salient points of a generic contour in the i-th frame are motion-compensated in the (i+1)-th frame. To improve robustness of motion-compensation and to reject false edge correspondences a capture mask is applied on the edge on frame i and compared to the estimated edge on frame i+1. The capture mask is defined around the same contour, and it is motion compensated according to the salient point motion (fig.4). Then, if the contour passing through the motion-compensated points in the the (i+1)-th frame is contained in the motion compensated capture mask, it is accepted as motion-compensated contour. If it is not entirely contained in the capture mask, it is rejected. This allows moderate contour modification frame by frame along the sequence.

The colour based segmentation procedure described above permits to relate contours to objects and therefore to perform object tracking.

In fig.5, the tracking of an object in a sequence using the whole edge motocompensation procedure is shown. This sequence presents a quite critical situation, since the considered object (ball) does not present emergent salient points, and bifurcations occur due to the presence of the background contours. Nevertheless, long term tracking is experienced.
4. Conclusion

Analysis of the contour curvature not only allows to locate salient points useful for object tracking, but also provides simple means for object classification. In particular, the persistence of specific structures through a sequence of frames is simply assessed by verifying the shape of its curvature plot. Applications of object tracking and recognition as well as of dynamic events detection based on the presented technique are currently under study.

\[\text{Figure 4. Capture mask.}\]
Figure 5. Result of tracking of an object (ball) in “children” sequence.
References


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