Visually Significant Dynamics for Watershed Segmentation

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Abstract

The watershed transform is a powerful tool for segmentation once we can deal with oversegmentation. To solve the oversegmentation problem, hierarchical approaches are considered in order to retain the most significant regions of the image at different scales. The dynamics of the regional minima have been used to build this hierarchy.

In this paper we present a new measure for computing the dynamics of the minima based on human perception of shapes. The described technique solves the major drawbacks of the hierarchical segmentations based on contrast dynamics or volume dynamics.

1. Introduction

Image segmentation is an important task in computer vision that aims to partition the image into physically meaningful regions. The ultimate goal is that this partition identifies the objects of interest in the input image. Morphological segmentation techniques [1] are quite successful. In morphological segmentation, the watershed transform [2] plays a key role as a tool for decomposing an image into regions with certain properties. The main problem of watershed transform is its sensitivity to intensity variations, resulting in oversegmentation. Two approaches are proposed in the literature to overcome this drawback: the selection of markers [3], and hierarchical approaches [1]

Although the use of markers has been successful in some segmentation applications, their selection requires either careful user intervention or explicit prior knowledge of the image structure. We focus on hierarchical approaches because our objective is to segment generic images and do not have any 'a priori' knowledge about them.

Grimaud [4] introduced the concept of the dynamics of minima that assign to each regional minimum a measure of its contrast. This concept can be extended to other measures such as area or volume [5]. Segmentations using contrast dynamics give as a result, partitions with a large amount of tiny regions that are not really visually significant. Volume dynamics solve this problem, but have the drawback that, usually, the segmentation process splits big homogeneous regions, and in the result image appear contours that are not visually significant.

In this paper we present a technique based on dynamics that aims to solve the trade-off between contrast and volume dynamics. The final objective of this work is to obtain partitions where neither insignificant regions nor insignificant contours are present. We will present a hierarchical watershed segmentation based on a new measure of the dynamics determined by a function of contrast dynamics and area dynamics. The regions obtained in the final segmented image using our approach have a higher visual significance, accordingly with the theories of human visual perception of areas.

2. Hierarchical segmentation

Our main goal is to create a hierarchy among the gradient watersheds that preserves the topology of the watershed lines at the finest scale in the scale-space stack and extracts homogenous objects for a larger scale. Let us define what is a hierarchy. Let $P^0 = \{S_1, S_2, ..., S_n\}$ be the initial partitioning of the image at the finest scale after the application of the watershed transformation. A hierarchical level k (HL_k) is defined as the partitioning $P^k = \{S_1^k, S_2^k, \ldots, S_{mk}^k\}$ which preserves the inclusion relationship $P^k \supseteq P^{k-1}$, implying that each segment of the set P^k is a disjoint union of segments from the sets P^{k-1}. A hierarchy of partitions is defined as a family which consists on all the hierarchical levels HL_k, where $k \in [0,k]$. It corresponds to a hierarchy of Region Adjacency graphs, $G_k(P^k, A^k)$, that are generated by applying successive mergings.

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There have been proposed different approaches for constructing a hierarchy of partitions defined on the basis of the watershed transformation that retrieve information from the superficial image structure: the waterfall algorithm [6], the dynamics of minima [4], the extinction values [5], and the dynamics of contours [7]. Essentially, this hierarchy can be interpreted as a set of region adjacencies, wherein an ordering is determined by a valuation, which can be controlled by the relative altitudes of the regional minima. The extinction value introduces area to the concept of dynamics. Comparisons of these approaches can be found in [8], [9].

The dynamics of a regional minimum is defined as the minimal climb required for a path starting from a regional minimum to reach another one with strictly lower altitude, the climb being the difference in altitude between the highest point of the path and the regional minimum under study. The contrast dynamics of regional minima of image I, *Rmin(I)*, will be denoted by $H_{dyn}[Rmin(I)]$. They are formally defined [10] by:

$$H_{dyn}[R\min(I)] = \min\{\max_{S\in[0,1]}[I(\gamma(S)) - I(\gamma(0))]:$$

$$\gamma:[0,1]\rightarrow\Re^2, I(\gamma(1)) < I(\gamma(0)), I(\gamma(0))\in R\min(I)\}$$

where γ is a path linking two points

Obviously, the dynamics of the global minimum is undefined, as there is no pixel with strictly lower altitude, so this minimum is often assumed to have a dynamics of infinite value or a dynamics equal to the dynamics of the image, that is, the difference between the maximum and the minimum values of the pixels in the image.

Regional minima with highest dynamics will be used as markers for watershed segmentation. By thresholding $H_{dyn}[Rmin(I)]$ with increasing values, a hierarchy is obtained. Figure 1.b shows the result of the watershed segmentation of figure 1.a using the 100 highest valued dynamics as markers. It is not a good result according to human visual significance; the regions obtained do not correspond to the 100 most outstanding regions in the image. Only contrast has been taken into account and a lot of tiny regions are obtained in the partition.

In order to solve this problem, Vauchier and Meyer [5] proposed the extinction values measure, which are dynamics based on other measures, obtaining by this means hierarchies with other criteria. The area dynamics is a size criterion, and the volume dynamics has been always presented as a trade-off between the contrast and the size of a region

The volume dynamics is defined as the volume that a catchment basin has to raise to reach another regional minima with a higher volume dynamics. The volume dynamics of regional minima of image I, *Rmin(I)*, will be denoted by $V_{dyn}[Rmin(I)]$

Figure 1.c shows the result of the segmentation using the 100 highest volume dynamics as markers. It can be seen that the regions obtained are closer to the human perception, but it has the unpleasant property that big homogenous regions are splitted. In the segmented image background appear some contours that are not visible for a human in the original image. A possible solution to solve this problem is presented in [11]. In that work, they remove the contours with a contrast under a given threshold, but this solution needs an additional parameter that must be tuned by the user.

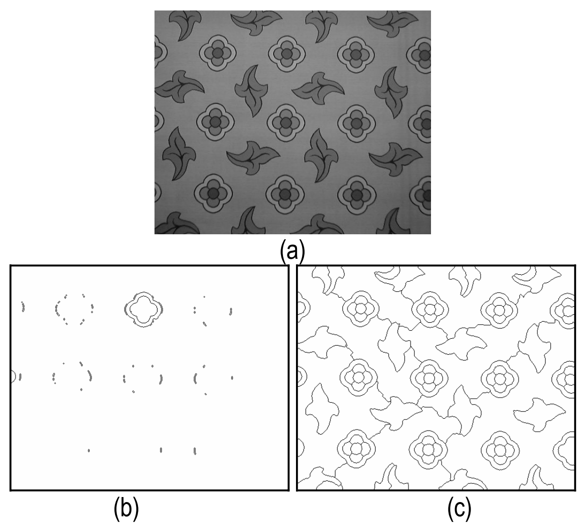


Figure 1. (a) Original image. (b). partition using Hdyn. (c) Partition using Vdyn

Using contrast dynamics we obtain in the result image, tiny regions that are no perceptible to humans. Using volume dynamics we obtain visually insignificant contours. In next section we present a new technique that solves this problem.

3. A new measure for dynamics

Psychological studies [12] state that our minds perceive lengths quite accurately, but perceive areas as being smaller than they actually are. There are several fundamental laws of human perception that explains the effective dimensionality of a visual feature. For example, Steven's Law [13], also called Steven´s Power Law, characterizes the difference between perceived magnitude and physical magnitude of a visual feature (as well as other sensory stimuli). Steven's Law predicts that the perceived scale is the actual physics scale to a power β , where β varies between 0.6 and 0.9 depending from person to person.

In our work we have redefined the dynamics of the regional minima in order to obtain values that are closer to the perceived scale. Accordingly to Steven's Power Law we define the visually significant dynamics (VS_{dyn}) as:

$$VS_{dyn}[Rmin(I)] = H_{dyn}\,[Rmin(I)] * (A_{dyn}[Rmin(I)])^{0'6}$$

Where $A_{dyn}[Rmin(I)]$ are the area dynamics. They are obtained by an algorithm based on an image extrema propagation scheme, and is directly deduced from the algorithm definition of area openings proposed by Vincent [14]. The grayscale area opening of size λ denoted $\gamma_\lambda^a(I)$ is given by :

$$\gamma_\lambda^a(I)(x) = \sup\left\{h \geq f(x) \middle| Area(\gamma_x^c(T_h(f))) \geq \lambda\right\}$$

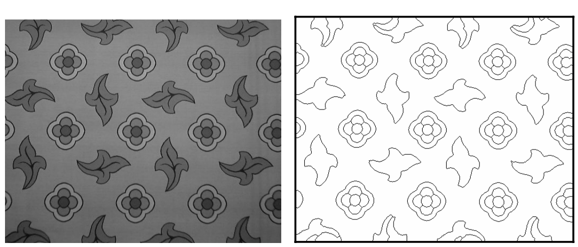
The VS_{dyn} obtained are used to establish the hierarchy for the watershed transform. The markers are obtained by suppressing the regional minima with VSdynamics lower than a constant value T. The standard algorithm to do this operation [15] is to compute the geodesic reconstruction by erosion of I_T over I where $I_T(a) = I(a)+T$.

$$E_I^\infty(I_t) = \left(I\Theta_{I_T} B_C\right)^\infty$$

$$I\Theta_{I_T} B_C = \left(I\Theta B_C\right) \wedge I_T$$

being Bc a disk shaped structuring element

Figure 2.b shows the resulting partitioned image. It can be noticed that the problems present in figure 1.b (presence of insignificant regions) and figure 1.c (presence of insignificant contours) are not present in the result image. The image has been partitioned into the 100 most significant regions. This is the number of regions that a human would approximately quantify when looking at figure 2.a. The value of the constant T is automatically determined by the one that thresholds the 100 highest VSdynamics of the image.



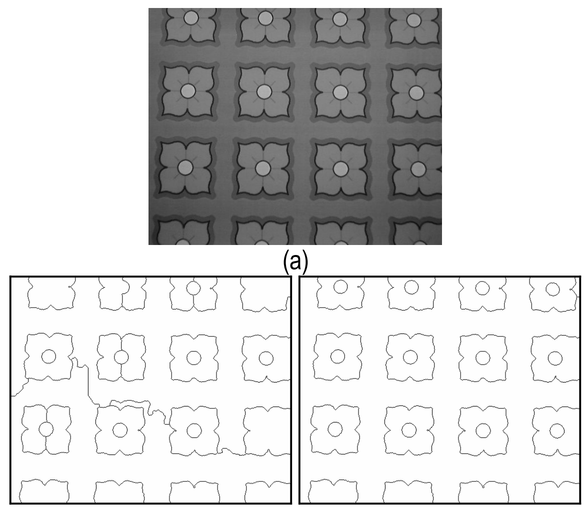
(a) (b)

Figure 2. (a) Original image.(b).partition using VSdyn

4. Results

To test our results we have used the UEA image database that can be found in [16] and is described in [17]. These images have been selected because their segmentation by visual judgment is obvious, so they are an excellent testbed for segmentation algorithms based on shape features. They are real images but the real physically meaningful regions are not context dependent

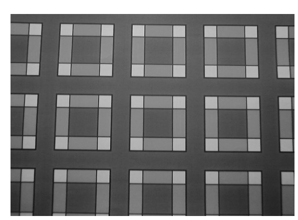
Figure 3.b shows the partition of figure 3a using the volume dynamics. According to visual judgment, there have been selected as markers the 30 regional minima with highest *Vdyn*. It can be seen that some big regions are incorrectly partitioned. Figure 3c show the results selecting the 30 regional minima with highest Vsdyn.



(b) (c)

Figure 3. Top: Original image. Bottom left :. result using Vdyn.Bottom right result using VSdyn

Figure 4.b shows the 100 most important regions of figure 4.a according to volume dynamics. Figure 4c shows the result using visually significant dynamics.



(a)

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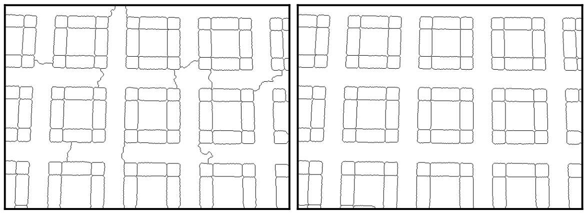

(b) (c)

Figure 4. Top: Original image. Bottom left :. result using Vdyn.Bottom right result using VSdyn

5. Conclusions

In this paper we have presented a new measure of the dynamics of the minima. Contrast dynamics present the problem that resulting regions in the final partition are very significant in altitude, but are insignificant for a human visual judgment. Volume dynamics present the problem that partitions big regions in the segmented image, and then, the result presents contours that are also invisible for us. The segmented image obtained using the volume dynamics needs a post-processing in order to remove contours with a contrast lower than a given threshold. This threshold must be tuned by the user and this is an undesirable fact in image segmentation.

The solution presented in this paper solves the trade-off between contrast and volume dynamics. It has been based on the psychological theories about human visual perception of areas. The results obtained are closer to the human visual judgment.

6. Acknowledgement

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7. References

[1] F.Meyer "An Overview of Morphological Segmentation", International Journal of Pattern Recognition and Artificial Intelligence, 15 (7), pp.1089-1118, 2001

[2] S.Beucher and C. Lantuéjoul. "Use of watershed in contour detection", Pro. Int. Workshop Image Processing, Real-Time Edge and Motion Detection/Estimation, 1979

[3] F.Meyer, S.Beucher, "Morphological segmentation". Journal of visual communication and image representation, 1 (1), pp.21-46, 1990.

[4] M.Grimaud, "New Measure of Contrast: Dynamics", Image Algebra and Morphological Processing 3, San Diego, Proc. SPIE, 1992

[5] C.Vauchier, F.Meyer. "Extinction Values: A new measurement of Persistence". IEEE Workshop on Non Linear Signal/Image Processing. pp. 254-257, 1995

[6] S. Beucher, "Segmentation d'images et Morphologie Mathematique", Ph.D.dissertation. Ecole nationale supérieure des mines de Paris, Fointeneblau, 1990.

[7] L.Najman, M. Schmitt, "Geodesic saliency of watershed contours and hierarchical segmentation" IEEE trans. Pattern Anal. Machine Intell., vol 18, pp.1163-1173,1996.

[8] F. Meyer, "hierarchies of partitions and morphological segmentation", in scale-space and Morphology in Computer Vision, M. Kerckhove Ed., New York, Springer, pp.161-182.

[9] S. Beucher, "Watershed, hierarchical segmentation and waterfall algorithm", Mathematical Morphology and its Applications to Image Processing, J.Serra ed., Norwell, Kluwer 1994, pp.69-76.

[10] M.Griamud, "La Géodésie numérique en morphologie mathématique: Application à la Détection automatique de microcalcifications en mammographie numérique", Phd Thesis, École des mines de Paris, 1991.

[11] B. Marcotegui, S. Beucher, "Fast implementation of waterfall based on graphs", Proc. Int. Symp on Mathematical Morphology, pp.177-186. Paris, 2005

[12] M. Kosslin, "Image and Mind", Harvard University Press, 1980

[13] H. Clarence, "vision and Visual Perception", John Wiley & Sons, 1965

[14] L. Vincent. "Morphological area opening and closings for grayscale images". Shape in picture, NATO workshop, Driebergen, 1992.

[15] J.Serra. "Image analysis and mathematical morphology", Theoretical Advances, Academic Press,1988

[16]http://www2.cmp.uea.ac.uk/Research/groups/compvis/CGmainData.htm

[17] G.Finlayson, G. Schaefer, G.Y.Tian, The UEA uncalibrated colour image database, Technical report SYS-C00-07, School of information Systems, University of East Anglia, Norwich, UK, 2000

[18] O.F.Olsen and M.Nielsen, "Multi-scale gradient magnitude watershed segmentation", Int. Conf. on Image Analysis and Processing (ICIAP'97),pp.6-13,1997