Multi-scale Tensor Vector Field Active Contour

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Introduction:

- Active Contours are a set of methods in which a contour is initialized near an object of interest, and the contour converges to the boundary of the object.
- The convergence is achieved by iteratively minimizing the energy of the contour.
- The energy of the active contour is guided by the following two rules.
  - Internal energy: Prior constraints on the contour, for example to limit stretchability and high curvature.
  - External energy: A forcing function to attract the contour towards the object of interest. We are proposing a multi-level external filed to improve the active contour accuracy.
- Two main challenges of active contours are the sensitivity to image noise and the capture range.
- The external field plays an important role in addressing these limitations. Three commonly used external fields: Gradient Vector Field (GVF), Vector Field Convolution (VFC), and Tensor Vector Field (TVF).

Objective and Key Idea:

Image noise adversely affects the localization of the external field at an object boundary, and the probability of distraction for an initial contour increases with increasing distance from the object boundary. However subsampling an image leads to noise reduction, which should lead to better active contour estimation. Therefore to improve the performance of active contours in the presence of noise, we propose a multi-scale tensor vector field (MTVF), generated by applying TVF to a multi-scale image.

Tensor Vector Field:

The contour deforms with the iterative minimization of its energy equation given as

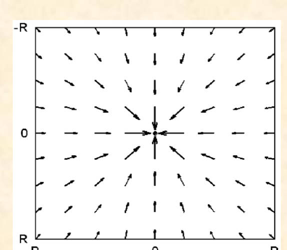
$$E_{AC} = \int_0^1 \left[E_{int}(c(s)) + E_{ext}(c(s)) \right] ds$$

E_{int} is the internal energy and E_{ext} is the external energy field. In VFC, the external field is generated by convolving an image edge-map with an anisotropic vector field kernel $\hat{\mathbf{k}}$ (R × R). The kernel ($\hat{\mathbf{k}}$) is generated by convolving a fixed vector field kernel $\mathbf{k}$ with the image tensor Γ,

For a vector field kernel, a vector $\mathbf{k}(i, j)$ at a co-ordinate (i, j) with respect to the kernel's center is expressed as

$$\mathbf{k}(i,j) = \mathbf{n}(i,j)m(i,j)$$

where $\mathbf{n}$ is the unit vector and m is the magnitude.



Vector Field Kernel (**k**)

The image tensor Γ for a pixel (x, y) is expressed as

$$\Gamma_{x,y} = \begin{pmatrix} \sigma_{x,x} & \sigma_{x,y} \\ \sigma_{y,x} & \sigma_{y,y} \end{pmatrix} \qquad \sigma_{x,y} = \sum_{i=-\kappa/2}^{\kappa/2} \sum_{j=-\kappa/2}^{\kappa/2} g(i,j) u_x(i,j) u_y(i,j)$$

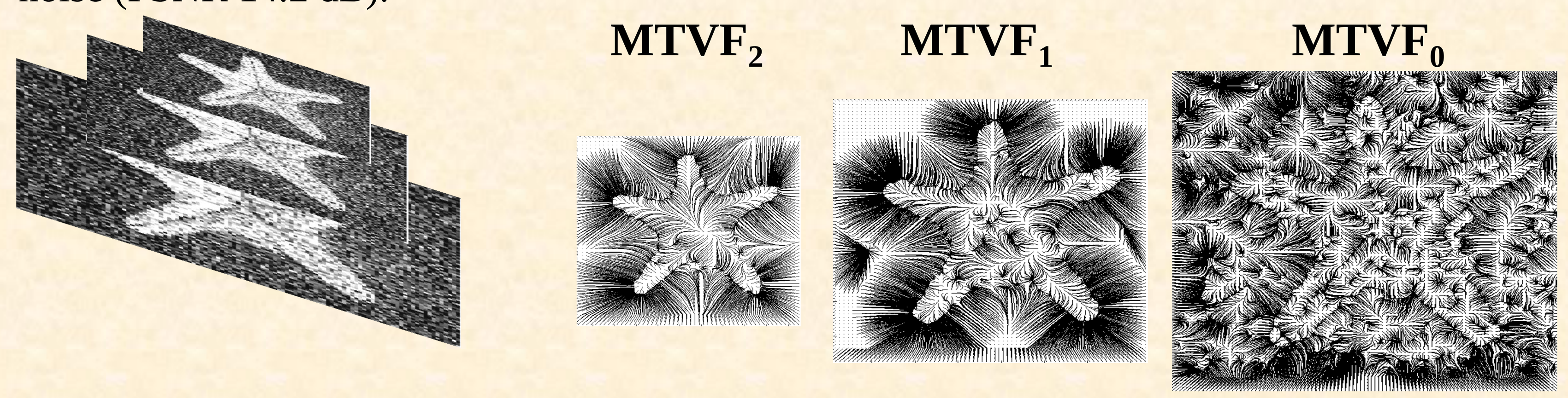
$\sigma_{x,y}$ is a weighted variance or co-variance matrix for each pixel (x, y) in the image, g is a Gaussian mask ($\kappa \times \kappa$). During convolution each element of the kernel $\mathbf{k}$ is modified using the major eigenvalue (λ_+) and major eigenvector ($\mathbf{v}_+$) of Γ as given below.

$$\hat{\mathbf{k}}(i,j) = |\mathbf{n}(i,j) \cdot \mathbf{v}_+(i,j)| \lambda_+(i,j) \mathbf{n}(i,j)$$

Multi-scale TVF:

- An image pyramid is created using a bi-cubic function.
- An active contour is initialized at original scale and resized to the smallest scale.
- Active contour is obtained at the lowest level ($MTVF_2$) using TVF.
- The final active contour at level L is used as an initial contour for level L-1 to get the final active contour at level L-1.

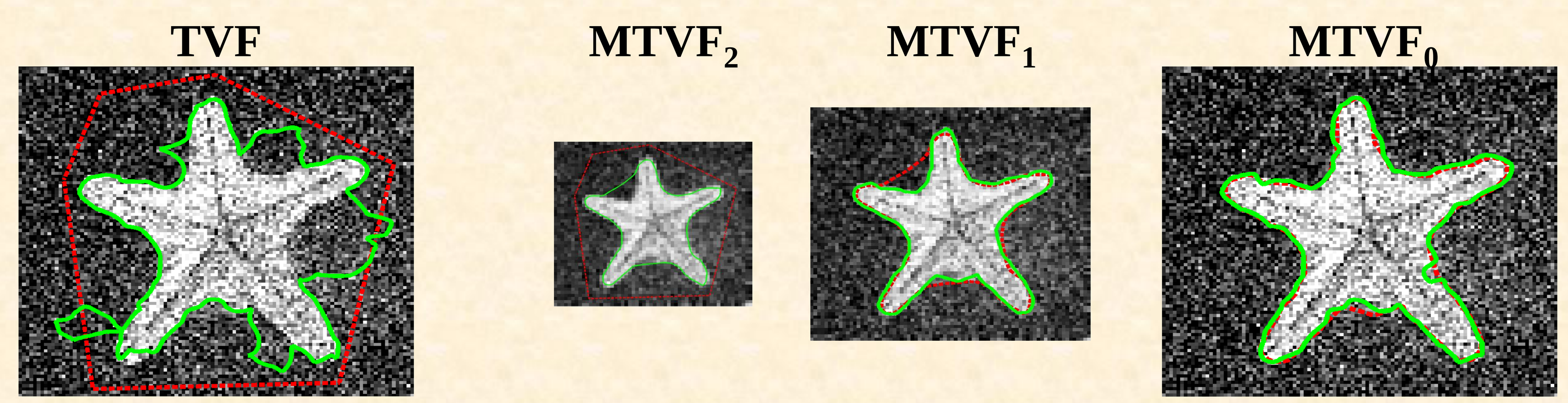
Showing external energy field for three scales of a starfish image corrupted with Gaussian noise (PSNR 14.2 dB).



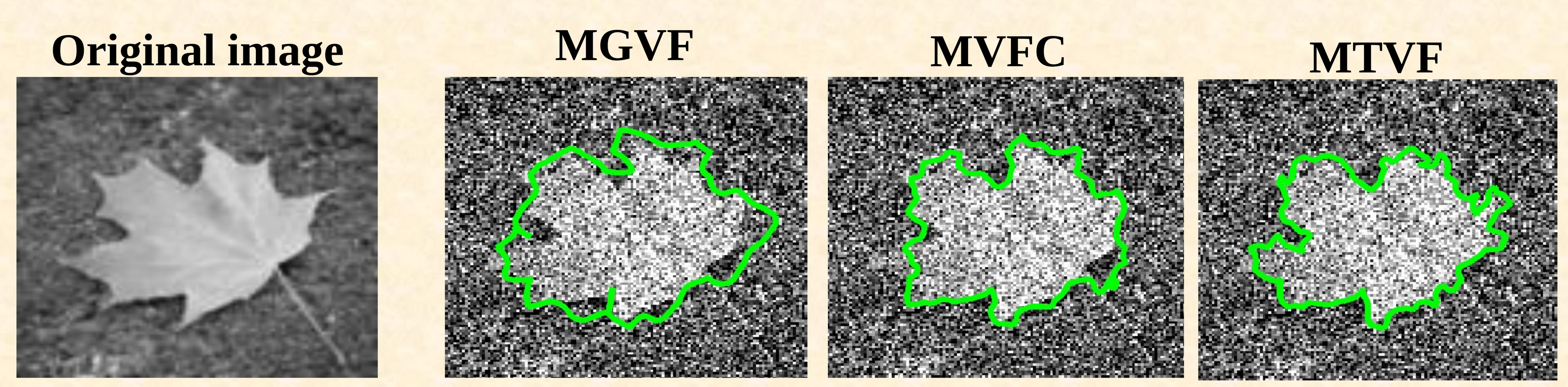
- A high density and low irregularity of the field lines (shown in black) implies a better pulling of the active contour towards the boundary.
- At the lowest scale ($MTVF_2$) the external field is least affected by noise.

Experimental Results:

- A comparison of TVF and MTVF for the starfish image contaminated with 14.2 dB Gaussian noise. Each MTVF stage is shown. The red curve is the initial contour and the green curve is the final contour.
- The final contour of $MTVF_0$ is far less distracted by noise as compared to TVF.



- A comparison of multi-scale GVF (MGVF), multi-scale VFC (MVFC), and MTVF based active contour for the maple leaf image corrupted with 12.3 dB Gaussian noise.
- The MTVF is much more robust against image noise than other methods.



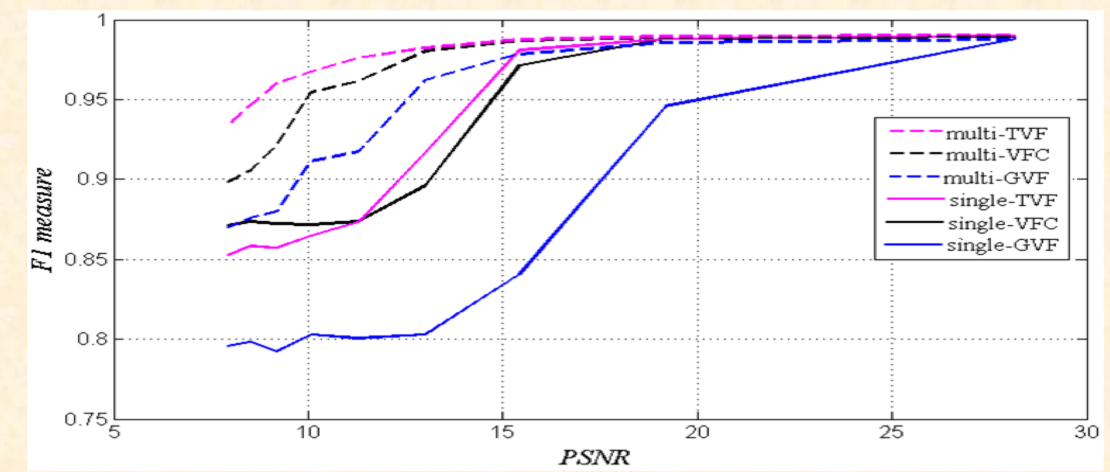
Acknowledgements:

This work is supported through funding from the Natural Sciences and Engineering Research Council of Canada.

Experimental Results (Cont.):

- Results are shown for the starfish image, corrupted with Gaussian noise.
- Twenty runs are used to collect consistent statistics.
- Results are compared using the F1-measure.

F1-measure vs. PSNR



- Multi-scale active contours always gives better performance than single scale active contour.
- MTVF accuracy stays stable till very high noise in the image.

F1-measure for sample images.

Image	PSNR	F1 measure(mean ± standard deviation)					
		GVF	MGVF	VFC	MVFC	TVF	MTVF
	10.6	0.82	0.92	0.89	0.95	0.90	**0.96**
	10.8	0.90	0.96	0.93	0.96	0.95	**0.97**
	12.9	0.93	0.96	0.93	0.96	0.94	**0.97**
	12.9	0.92	0.94	0.92	0.95	0.92	**0.96**
	13.3	0.89	0.95	0.89	0.96	0.90	**0.98**
	14.8	0.92	0.95	0.93	0.97	0.93	**0.98**

- For multi-scale, three levels are used and for each level 5 iterations of active contours are run. For single-scale, 30 iterations are run.
- MTVF based active contours consistently outperformed other methods.
- Multi-scale approaches performs better than their single scale counterparts.

Conclusions:

- Coarser scales of a multi-scale decomposition are less affected by noise, so the corresponding external field is more noise robust, and produces a good contour estimate..
- In general, the multi-scale active contour algorithms are faster: at coarser scales the images are smaller, making iterations faster, and at finer scales the contour is initialized by the coarser scale to be close to the object boundary, requiring fewer iterations.
- Of the multi-scale methods implemented, the multi-scale TVF exhibited excellent performance, superior to any other method tested.

Reference:

- A. Kumar, A. Wong, A. Mishra, D. A. Clausi, and P. Fieguth, "Tensor vector field based active contours", in ICIP, 2011.
- A. Mishra, P. Fieguth, and D. A. Clausi, "Decoupled Active Contour (DAC) for Boundary Detection" in IEEE PAMI, Volume 33(2), pages 310-324, Feb. 2011.