# RAIN STREAKS REMOVAL FOR SINGLE IMAGE VIA DIRECTIONAL TOTAL VARIATION REGULARIZATION

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## INTRODUCTION

We exploit the directional smoothness of rain streaks for the single-image rain streaks removal and propose a convex model that uses the directional total variation (DTV) to characterize the smoothness of rain streaks in arbitrary orientations. The proposed model consists of four terms: the fidelity term, the l1 norm for the sparsity of rain streaks, and two DTV regularization terms for the directional smoothness and the piecewise smoothness of rain streaks and rain free backgrounds, respectively. To solve the proposed model, we develop an efficient algorithm based on the alternating direction method of multipliers (ADMM) framework. Extensive experimental results on both synthetic and real rainy images demonstrate the superiority of our method.

## OUR CONTRIBUTIONS

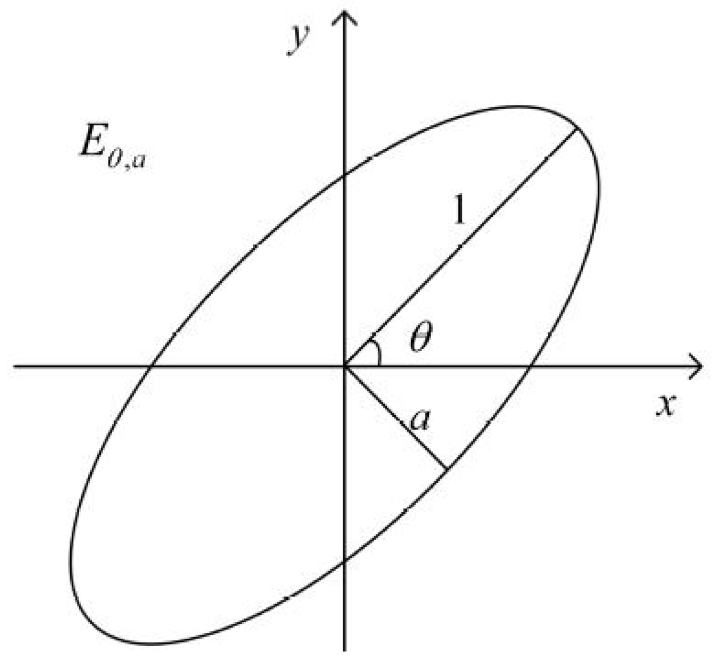
- We consider the directional smoothness of oblique rainstreaks, and propose a convex model utilizing DTV to characterize the smoothness of rain streaks in arbitrary directions. To the best of our knowledge, our work is the first attempt to bring DTV regularization in rain streaks removal task.
- To tackle the proposed model, we develop an efficient algorithm based on the alternating direction method of multipliers (ADMM) framework where the convergence can be theoretically guaranteed. Extensive experiments demonstrate the superiority of our method visually and quantitatively.

## DIRECTIONAL TOTAL VIRIATION (DTV)

- For a discrete-space image **X**, the total variation (TV) of **X** can be written as :

$$\mathrm{TV}(\boldsymbol{X}) = \sum_{i,j} \|\nabla \boldsymbol{X}(i,j)\|_2 = \sum_{i,j} \sup_{\boldsymbol{v}\in B_2} \langle \nabla \boldsymbol{X}(i,j), \boldsymbol{v}\rangle,$$

where **v** is a vector, and $B_2$ is the unit ball centered at origin.




- By replacing $B_2$ with a closed elliptical set, $E_{\theta,a}$, which is centered at origin and oriented along the direction (cosθ, sinθ), (0<θ<180˚) with the unit major semi-axis and minor semi-axis a, (0<a<1), we can get the following directional total viriation (DTV)

$$\mathrm{DTV}_{\theta,a}(\boldsymbol{X}) = \sum_{i,j} \|\widetilde{\nabla}_{\theta,a} \boldsymbol{X}(i,j)\|_2 = \sum_{i,j} \sup_{\boldsymbol{v}\in E_{\theta,a}} \langle \nabla \boldsymbol{X}(i,j), \boldsymbol{v}\rangle,$$

where $\widetilde{\nabla}_{\theta,a}$ the directional gradient oerator defined as

$$\widetilde{\nabla}_{\theta,a} \boldsymbol{X}(i,j) = \begin{pmatrix} \nabla_\theta \boldsymbol{X}(i,j) \\ a\nabla_{\theta^\perp} \boldsymbol{X}(i,j) \end{pmatrix} = \Lambda_a T_{-\theta} \nabla \boldsymbol{X}(i,j),$$

and

$$\Lambda_a = \begin{pmatrix} 1 & 0 \\ 0 & a \end{pmatrix}, T_{-\theta} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}.$$

## OUR MODEL

$$\min_{\boldsymbol{O},\boldsymbol{R}} \frac{1}{2}\|\boldsymbol{O}-\boldsymbol{B}-\boldsymbol{R}\|_F^2 + \lambda_1 \sum_{i,j} \|\widetilde{\nabla}_{\theta,a_1} \boldsymbol{R}(i,j)\|_2 + \lambda_2 \|\boldsymbol{R}\|_1 + \lambda_3 \sum_{i,j} \|\widetilde{\nabla}_{\theta^\perp,a_2} \boldsymbol{B}(i,j)\|_2$$
$$s.t. \quad 0 \le \boldsymbol{B} \le \boldsymbol{O}, 0 \le \boldsymbol{R} \le \boldsymbol{O},$$

- **O**, **B**, and **R** are the observed rainy image, clean image, and the rain streaks, respectively.
- This model is convex. An efficient algorithm based on ADMM framework is employed to solve it.

## EXPERIMENTS

- **Experiments on 50 images of BSD500 dataset.**

(a) GT (b) Rainy (c) GMMLP (d) CNN (e) UGSM (f) DTVRS

**The mean PSNR and SSIM.**

| Metrics | rainy | GMMLP | CNN | UGSM | DTVRS |
|---|---|---|---|---|---|
| PSNR | 23.7936 ± 1.1749 | 28.4303 ± 1.4479 | 24.2219 ± 1.2437 | 26.1925 ± 2.0719 | **29.3313 ± 1.7251** |
| SSIM | 0.8405± 0.0690 | 0.9259 ± 0.0326 | 0.8675 ± 0.0580 | 0.8966 ± 0.0435 | **0.9306 ± 0.0291** |

- **Experiments on real rainy images.**

(a) Rainy (b) GMMLP (c) CNN (d) UGSM (e) DTVRS