Removing Raindrops from a Single Image using Synthetic Data

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Abstract

We simulated the exact features of raindrops on a camera lens and conducted an experiment to evaluate the performance of a network trained to remove raindrops. In this study, we focused on generating raindrop shapes that are closer to reality with After categorizing raindrops by type, we further separated each raindrop type into its constituent elements, generated each element separately, and finally combined the generated elements. The evaluation results proved that images with synthetic raindrops can be used as training data for real-world images.

Raindrop Formulation

We divided the raindrops into two types, and simulated the state of each type separately.

A) Normal raindrop

We break raindrops down into the following four constituent elements.

- \( h_i \): caused by the thickness of raindrops
- \( k \): secondary lens effect
- \( s \): effect by the raindrop itself
- \( h_s \): simulated light reflection

spherical distortion: coordinate transitions in the ROI caused by secondary lens effect

\[ x' = R \cdot \cos \left( \arctan \left( \frac{y}{x} \right) \right) \cdot \sin \left( \frac{\pi \sqrt{2x^2 + y^2}}{2R} \right) \]

\[ y' = R \cdot \sin \left( \arctan \left( \frac{y}{x} \right) \right) \cdot \sin \left( \frac{\pi \sqrt{2x^2 + y^2}}{2R} \right) \]

wave distortion: shape of a raindrop can also change as a result of gravity or by the camera being bumped during operation

\[ x' = A \cdot \cos (\theta_0 + \delta \cdot y), (x, y) = (x + x', y) \]

B) Glare raindrop

We break raindrops down into the following four constituent elements.

spherical distortion: spherical + wave

Glare raindrops

spherical distortion: coordinate transitions in the ROI caused by secondary lens effect

\[ x' = R \cdot \cos \left( \arctan \left( \frac{y}{x} \right) \right) \cdot \sin \left( \frac{\pi \sqrt{2x^2 + y^2}}{2R} \right) \]

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Raindrop Type Selection

We discovered through experience that the position of the ambient light has a considerable effect on generated raindrops type.

glare probability map: given the image size and the coordinate \((x, y)\) of the light source

\[ L_{ij} = I_{ij} + W \cdot D_{ij} \]

\[ D_{ij} = \max \left( \sqrt{(x-x_i)^2 + (y-y_i)^2} \right) \frac{(x-x_i) + (y-y_i)}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} \]

\[ W = \frac{1}{D_{ij}} \]

\[ D_{ij} = \sqrt{(x-x_i)^2 + (y-y_i)^2} \]

\[ 0 \leq i \leq w, \quad 0 \leq j \leq h \]

reference synthetic

Dataset & Experimental Setup

We evaluated two models proposed in AttentiveGAN(2018), and the lightweight version of that model. AttentiveGAN estimates raindrop position and uses it as an attention to focus on raindrops.

\( \alpha \) Collecting paired images from a real Water droplets were sprayed directly on the lens surface using a fixed camera to acquire paired images of the same background.

\( \beta \) Generating synthetic images

We implemented the generation of synthetic raindrops according to our proposed method as a tool.

GUI tool (CUI version also exists)

Experimental Result

evaluation result

<table>
<thead>
<tr>
<th>Training Dataset</th>
<th>Evaluation Method</th>
<th>Real (1,000pair)</th>
<th>Synthetic (1,000pair)</th>
<th>PSNR</th>
<th>SSIM</th>
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<tbody>
<tr>
<td>Full Model</td>
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restoration result visualized

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<tr>
<th>input</th>
<th>ground truth</th>
<th>real (1,000pair)</th>
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<tbody>
<tr>
<td>synthetic (1,000pair)</td>
<td>26.38</td>
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