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Compute-Aware Evaluation of Severity Conditioning and Lightweight Architectures for Real-World Image Deraining

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Volume: 27 Issue: 3 Page: 319-339
DOI: 10.31436/iiumej.v27i3.4689

Published SEP 2026

Indexed 2026-09-26

Document Type Article

Abstract

Image deraining for embedded perception must balance restoration quality against complete inference cost. Yet density-conditioned methods require annotations unavailable for captured rain, while efficiency studies often omit conditioning-signal cost. This study examines whether label-free severity conditioning justifies its end-to-end cost and whether complexity measures predict realized latency. Under a common L1 protocol, we compare a PReNet baseline with scalar feature-wise linear modulation, spatial severity modulation (SSM), a matched-capacity constant-map control, and two lightweight architectures. Zero-, shuffled-, and constant-prior interventions test SSM's dependence on prior presence, image correspondence, and spatial structure. Six models were trained for 100 epochs on 10,000 LHP-Rain patches using three seeds and evaluated on the 1,000-image test split. SSM achieved 31.775 $\pm$ 0.109 dB, compared with 31.741 $\pm$ 0.095 dB for Base and 31.754 $\pm$ 0.102 dB under zero-prior replacement. A seed-level equivalence analysis based on paired image differences supported practical equivalence between SSM and Base (95% CI: -0.026 to 0.094 dB; margin fixed before primary analysis: $\pm$ 0.1 dB), consistent with the half-scale experiment. The two-stage model reduced computation from 265.0 to 44.6 GFLOPs and model latency from 20.43 to 4.50 ms, but the prior generation increased total latency to 24.74 ms. CBAM-light required 14.1 GFLOPs yet recorded 33.68 ms. The label-free statistic achieved a cross-scene AUC of 0.772 on RealRain-1k, indicating moderate agreement with density labels. Thus, severity-conditioned and lightweight deraining systems should be assessed through verified prior use and measured end-to-end latency rather than accuracy, parameters, or GFLOPs alone.

Keywords

Author Keywords: [Image Deraining](#); [Severity Conditioning](#); [Lightweight Architectures](#); [End-to-End Real-World Rain](#)

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Categories/ Classification

Research Areas: Engineering

Web of Science Categories

[Engineering, Multidisciplinary](#)

Funding

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Funding agency	Grant number
AOARD	FA2386-25-1-4061
	SPI25-295-0295
IIUM	SPI25-295-0295

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Journal information

[IIUM ENGINEERING JOURNAL](#)

← [View Journal Impact](#)

ISSN 1511-788X

eISSN 2289-7860

0.26

Journal
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Indicator™
(2025)



Current Publisher	KULLIYAH ENGINEERING, INT ISLAMIC UNIV MALAYSIA, JALAN GOMBAK 53100, MALAYSIA
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Web of Science Categories	Engineering, Multidisciplinary

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