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Role of Image Restoration Algorithms for Intelligent Transportation Systems in Foggy Conditions

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Abstract: *Intelligent Transportation Systems have become an important component of modern transportation infrastructure by integrating artificial intelligence, computer vision, communication technologies, and automated decision-making systems. Vision-based ITS applications such as autonomous driving, traffic monitoring, vehicle detection, pedestrian recognition, and road safety analysis strongly depend on high-quality image information. However, adverse weather conditions, particularly fog and haze, significantly degrade image quality by reducing visibility, lowering contrast, changing color information, and weakening object features. Image restoration algorithms provide effective solutions for recovering visual information from degraded foggy images.*

During 2010–2021, image restoration research progressed from traditional atmospheric model-based methods to advanced deep learning approaches. Techniques such as Dark Channel Prior, Color Attenuation Prior, image fusion, convolutional neural networks, generative adversarial networks, and attention-based models have significantly improved image visibility and object recognition performance. This paper reviews the role of image restoration algorithms in foggy ITS environments, summarizes major developments between 2010 and 2021, compares different approaches, and discusses challenges and future research directions.

Keywords: Intelligent Transportation System, Image Restoration, Fog Removal, Image Dehazing, Autonomous Vehicle, Deep Learning, Computer Vision.

I. INTRODUCTION

The development of Intelligent Transportation Systems has transformed conventional transportation networks into smart, connected, and automated systems. ITS applications depend on image-based sensors including surveillance cameras, vehicle-mounted cameras, and roadside monitoring systems. These sensors provide essential information for traffic management, accident prevention, navigation, and autonomous vehicle operation.

However, environmental conditions such as fog, mist, haze, and smoke create serious challenges for image-based transportation systems. Fog particles scatter incoming light before it reaches the camera sensor, resulting in unclear images with poor contrast, reduced visibility, and missing details. These limitations affect the performance of vehicle detection, lane detection, traffic sign recognition, and autonomous driving systems.

Image restoration algorithms aim to recover the original scene information by removing atmospheric degradation. Recent research has classified image restoration approaches into enhancement-based, physical restoration-based, fusion-based, and learning-based methods. Deep learning approaches have become increasingly popular because of their ability to learn complex degradation patterns directly from large datasets.

II. FOGGY IMAGE FORMATION MODEL

Most fog removal algorithms are based on the atmospheric scattering model:

$$I(x) = J(x)t(x) + A(1 - t(x))$$

Where:
I(x) = observed foggy image
J(x) = original clear image
A = atmospheric light
t(x) = transmission map
The objective of restoration algorithms is to estimate the unknown parameters and reconstruct the clear image.
In ITS applications, accurate restoration is important because incorrect enhancement may negatively affect vehicle detection and autonomous decision-making.

III. IMPORTANCE OF IMAGE RESTORATION IN INTELLIGENT TRANSPORTATION SYSTEMS

1. Autonomous Driving

Autonomous vehicles require continuous environmental perception. Foggy conditions reduce camera performance, causing errors in obstacle detection and navigation. Image restoration improves visibility of vehicles, pedestrians, and road structures.

2. Traffic Surveillance

Highway and urban surveillance cameras frequently operate under changing weather conditions. Restoration techniques enhance monitoring accuracy during foggy periods.

3. Vehicle Detection and Classification

Object detection algorithms require clear edges and textures. Dehazing improves feature extraction and increases detection accuracy.

4. Lane Detection

Fog reduces the difference between road surfaces and lane markings. Restoration enhances road boundaries and improves lane tracking.

IV. EVOLUTION OF IMAGE RESTORATION ALGORITHMS

Table 1: Major Image Restoration Techniques Used in Foggy ITS Applications

Year	Algorithm	Method Category	Main Contribution	Application in ITS	Limitation
2010	Dark Channel Prior (DCP)	Prior-based restoration	Estimated haze using dark pixel statistics	Road visibility enhancement	Poor in bright areas
2011	Guided Filtering	Optimization-based	Improved transmission refinement	Edge preservation	Computational cost
2013	Boundary Constraint Method	Physical model	Improved atmospheric light estimation	Traffic surveillance	Parameter dependency
2014	Multi-scale Fusion	Fusion-based	Combined contrast and color enhancement	Vehicle cameras	Possible artifacts
2015	Color Attenuation Prior (CAP)	Prior-based	Depth estimation using brightness and saturation	Outdoor transportation images	Sensitive to illumination

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2016	DehazeNet	CNN-based	Learned transmission estimation	Autonomous vision systems	Requires training data
2016	MSCNN	Deep learning	Multi-scale feature extraction	Object recognition	High computation
2017	AOD-Net	End-to-end CNN	Direct image restoration	Real-time ITS	Generalization issues
2018	GAN Dehazing	Generative model	Realistic image reconstruction	Smart vehicles	Training instability
2019	Attention Networks	Deep learning	Region-focused restoration	Advanced driver assistance	Increased complexity
2020	NH-HAZE Dataset Methods	Benchmark-based	Real-world fog evaluation	Autonomous driving research	Limited samples
2021	Deep Learning Surveys	Review-based	Classification of modern methods	ITS research framework	Dataset dependence

V. TRADITIONAL IMAGE RESTORATION METHODS

I. Dark Channel Prior

He (2010) introduced the Dark Channel Prior approach, which became one of the most influential single-image dehazing techniques. The method assumes that most outdoor clear images contain pixels with very low intensity values in at least one color channel.

Advantages:

1. Does not require additional sensors.
2. Provides strong contrast improvement.
3. Effective for outdoor road images.

Limitations:

1. Poor performance in sky regions.
2. Sensitive to bright objects.
3. Requires significant processing time.

II. Color Attenuation Prior

Zhu (2015) proposed the Color Attenuation Prior method based on the observation that haze affects brightness and saturation. The method estimates depth information using color differences.

Advantages:

1. Simple mathematical structure.
2. Suitable for single images.
3. Improves scene depth perception.

Limitations:

1. Less effective under dense fog.
2. Depends on lighting conditions.

VI. IMAGE FUSION-BASED RESTORATION

Fusion-based methods improve visibility by combining multiple enhanced versions of an image.

Ancuti (2014) developed a multi-scale fusion framework that combines contrast enhancement and color correction. Such approaches are useful for ITS because they do not require complex atmospheric parameter estimation.

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Benefits:

1. Natural-looking output.
2. Suitable for real-world images.
3. No requirement for training data.

Drawbacks:

1. Limited physical haze removal.
2. Computational complexity.

VII. DEEP LEARNING-BASED RESTORATION ALGORITHMS

I. DehazeNet

Cai (2016) introduced DehazeNet, a convolutional neural network model designed to estimate transmission maps automatically.

Role in ITS:

1. Improves object visibility.
2. Supports vehicle recognition.
3. Enhances road scene analysis.

II. Multi-scale CNN

Ren (2016) proposed a multi-scale CNN framework that extracts haze features at different image resolutions.

Advantages:

1. Better structural recovery.
2. Improved restoration accuracy.

III. AOD-Net

Li (2017) proposed All-in-One Dehazing Network (AOD-Net), which directly learns the mapping between foggy and clear images.

ITS Advantages:

1. Faster processing.
2. Suitable for embedded systems.
3. Supports real-time applications.

IV. GAN and Attention-Based Methods

GAN-based restoration methods generate visually realistic haze-free images, while attention mechanisms focus on important image regions affected by fog.

Recent surveys indicate that deep learning-based dehazing methods can be divided into supervised, semi-supervised, and unsupervised categories.

Table 2: Comparison of Image Restoration Approaches for Foggy ITS

Method	Input Requirement	Training Required	Accuracy	Real-Time Capability
Histogram Enhancement	Single image	No	Moderate	High
DCP	Single image	No	High	Medium
CAP	Single image	No	Medium	High
Fusion Methods	Multiple enhanced images	No	High	Medium
CNN Methods	Large datasets	Yes	Very High	Medium

GAN Methods	Large datasets	Yes	Very High	Low-Medium
Lightweight CNN	Dataset-based	Yes	High	High

VIII. EVALUATION METRICS FOR FOG RESTORATION

Performance of restoration algorithms is evaluated using:

Metric	Purpose
PSNR	Measures image reconstruction quality
SSIM	Evaluates structural similarity
MSE	Measures restoration error
NIQE	No-reference quality assessment
Object Detection Accuracy	Measures ITS performance
Processing Time	Evaluates real-time suitability

Visibility restoration studies emphasize that evaluation should consider both image quality and downstream computer vision performance.

IX. CHALLENGES IN FOGGY ITS IMAGE RESTORATION

1. Real-Time Processing

Autonomous vehicles require image restoration within milliseconds. Complex deep models often require high computational resources.

2. Real-World Fog Variability

Synthetic fog datasets cannot fully represent natural fog conditions.

3. Color Distortion

Some algorithms improve visibility but produce unrealistic colors.

4. Dataset Limitations

Deep learning models require large and diverse datasets for reliable performance.

X. CONCLUSION

Image restoration algorithms have become an essential technology for improving Intelligent Transportation Systems operating in foggy environments. Traditional methods such as Dark Channel Prior and Color Attenuation Prior provided important foundations for haze removal, whereas deep learning-based methods have significantly improved restoration quality and adaptability. Between 2010 and 2021, research shifted from manually designed atmospheric models toward intelligent learning-based frameworks capable of handling complex weather degradation. However, challenges related to real-time performance, dataset diversity, and environmental adaptation remain. Future ITS applications require lightweight, accurate, and adaptive image restoration systems to ensure safe and reliable transportation under adverse weather conditions.

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