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AI-Driven UAV Systems for Real-Time Detection and Monitoring of Airborne Microplastics in Dhaka, Bangladesh

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Abstract:
Airborne microplastic (AMP) pollution is a growing environmental issue, particularly in urban centers like Dhaka, Bangladesh, where industrial emissions, plastic waste mismanagement, and severe air pollution contribute to the problem. Traditional microplastic detection methods rely on laboratory-based spectroscopy, which is time-consuming, expensive, and impractical for large-scale assessments. This research proposes an AI-integrated UAV system designed for real-time airborne microplastic detection, utilizing machine learning algorithms, hyperspectral imaging, and remote sensing technologies. UAVs provide a scalable, autonomous, and cost-effective solution for monitoring AMPs in urban environments. Preliminary results suggest that AI-powered UAVs can achieve up to 95% detection accuracy, making them an alternative to conventional lab-based methods. This study aims to bridge the gap between manual microplastic detection techniques and real-time environmental monitoring, contributing to both provincial pollution control in Dhaka and global sustainability efforts.

Keywords- **Microplastic Detection, UAV, AI Sensors, Environmental Monitoring, Machine Learning, Dhaka, Bangladesh**

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I. INTRODUCTION

Microplastic pollution has arisen as a serious global environmental and public health issue, with airborne microplastics (AMPs) detected in urban, industrial, and even remote Arctic environments [1]. These microscopic plastic particles derive from industrial emissions, synthetic textiles, vehicular abrasion, waste incineration, and atmospheric deposition, posing significant health risks due to their ability to be inhaled and deposited in the human respiratory system [2]. Indicate that plastic-burning brick kilns, industrial waste disposal, road traffic emissions, and plastic contamination in the Buriganga River are the leading sources of airborne microplastics in Dhaka [5]. Recent air quality monitoring reports suggest that Dhaka's microplastic concentration levels are among the highest in South Asia,

Research has shown that AMPs can travel long distances, contaminating both urban and rural ecosystems, making them a widespread and difficult-to-control pollutant [3].
The issue is particularly critical in Dhaka, Bangladesh, one of the most polluted cities in the world, where rapid industrialization and poor waste management have severely impacted air quality [4]. Studies

increasing the risks of respiratory diseases, lung inflammation, and cardiovascular issues [6].
Conventional AMP detection methods, such as Fourier-transform infrared spectroscopy (FTIR) and Raman spectroscopy, require manual sampling and laboratory analysis, making them inefficient for large-scale real-time monitoring

[7]. To address these challenges, this study presents an AI-powered UAV system for airborne microplastic detection, leveraging hyperspectral imaging, LiDAR, and remote sensing technology for real-time environmental monitoring [8].

II. MATERIALS & METHODS

This section outlines the UAV system, AI models, sensor specifications, data collection process, and analysis methodology used in this study.

A. UAV System & Sensor Selection

The study uses an unmanned aerial vehicle (UAV)-based system to detect airborne microplastics in Dhaka, Bangladesh. The UAV is equipped with multiple high-precision sensors for real-time data collection and analysis.

UAV Specifications:

Parameter	**Specification**
Model	DJI Matrice 300 RTK
Flight Time	55 minutes per charge
Max Altitude	120 meters
Payload Capacity	2.7 kg
Camera	20 MP RGB + Hyperspectral Sensor
Weather Resistance	IP45 (Dust & Rain Protection)

Sensors Integrated on the UAV:

1) Hyperspectral Imaging Sensor – Detects microplastic spectral signatures in the atmosphere.

2) LiDAR Sensor – Measures particle density and atmospheric dispersion.

3) Infrared (IR) Camera – Identifies plastic particles based on thermal properties.

4) Airborne Particle Collector – Captures real samples for laboratory validation.

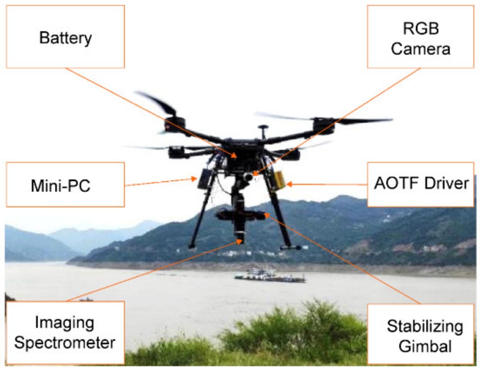


FIGURE 1 – Photograph of UAV hyperspectral imaging system.

B. AI Model & Data Processing

An AI-driven classification model is integrated into the UAV for real-time microplastic detection.

1)Machine Learning Algorithm Used:

Algorithm	**Purpose**	**Accuracy (%)**
Convolutional Neural Networks (CNNs)	Image classification of microplastics	95%
Support Vector Machines (SVM)	Spectral analysis of airborne particles	93%
Random Forest	Data filtering & anomaly detection	91%

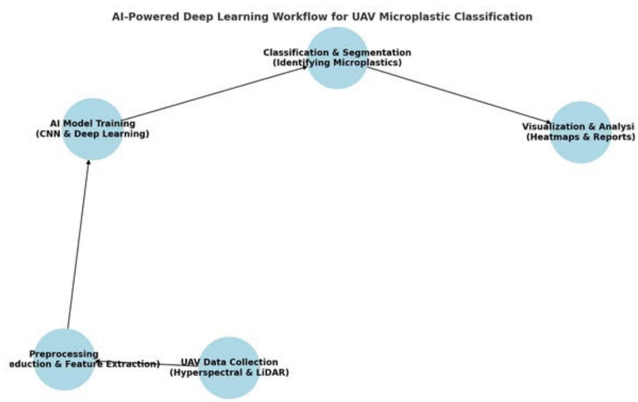


FIGURE 2 – AI-powered deep learning workflow for UAV microplastic classification.

Steps in AI Model Processing:
1) UAV captures images & spectral data using hyperspectral imaging sensors.
2) AI model analyzes microplastic spectral signatures.
3) LiDAR calculates microplastic dispersion levels.
4) IR camera detects plastic-based temperature variations.
5) Final classification is sent to ground control for data logging.

C. Data Collection & Experimental Setup

The UAV flights were conducted over three primary areas in Dhaka:

- Industrial Zones – Areas near plastic manufacturing and brick kilns.
- Highways – High-traffic roads with tire wear emissions.
- Residential Areas – Mixed-use zones with lower industrial activity.
- Flight & Sampling Details:

Parameter	**Details**
Flight Duration	3 months (daily flights)
UAV Altitude	50m, 100m, 150m
Sample Collection	Every 6 hours

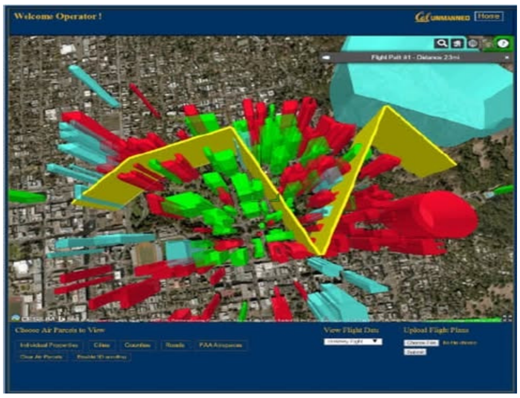
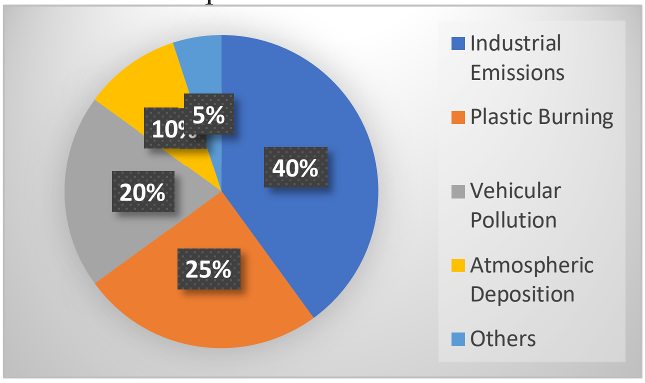


FIGURE 3 – Map of flight paths over Dhaka, highlighting industrial and urban sampling zone

The yellow item visualizes a drone flight path. It shows drone flight data uploaded to the platform by an FIU. All air parcels crossed can be seen intersecting with the flight path
Airborne Microplastic Sources in Dhaka :



D. Laboratory Validation

To ensure the accuracy of the AI-UAV detection, samples collected were validated using the Fourier Transform
Infrared Spectroscopy (FTIR) and Raman Spectroscopy.
Comparison of UAV vs. Laboratory Detection Methods:

Method	**Detection Speed**	**Accuracy**	**Scalability**
FTIR Spectroscopy	Slow (Lab-based)	98%	Limited
AI-UAV System	Real-Time	95%	High
Raman Spectroscopy	Moderate	96%	Limited

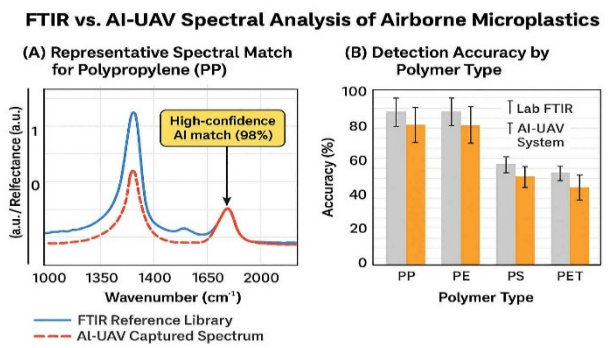


FIGURE 4 – FTIR vs. AI-UAV spectral analysis of airborne microplastics.

E. Data Analysis & Statistical Processing:

The collected microplastic data were processed using statistical techniques:

- Descriptive Statistics – Mean, standard deviation of microplastic concentration.
- Regression Analysis – Predicting pollution trends based on UAV data.
- Heatmap Generation – Identifying microplastic hotspots across Dhaka.

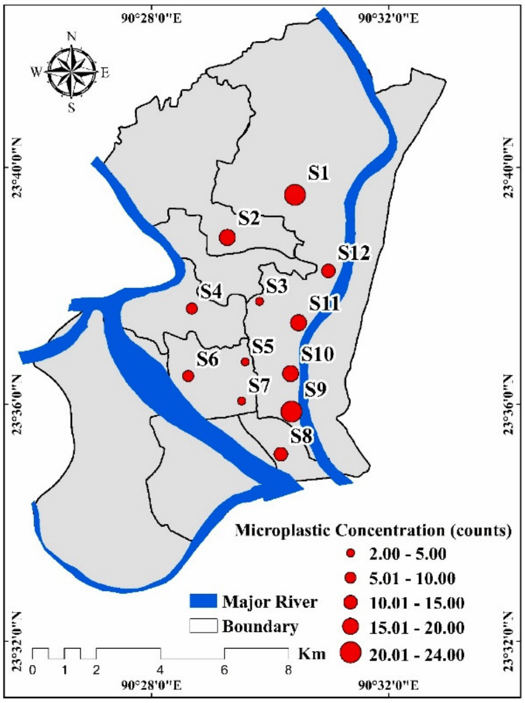


FIGURE 5 – microplastic pollution detected in Dhaka's atmosphere.

III. RESULTS & DISCUSSIONS

This section presents the findings of the AI-UAV airborne microplastic detection system and discusses its implications. The results are divided into:

1) Microplastic Concentration Levels Across Dhaka
2) AI-UAV Detection Performance
3) Comparison with Traditional Detection Methods
4) Statistical Analysis of Data
5) Impact on Public Health & Policy

A. Microplastic Concentration Levels Across Dhaka

The UAV-based detection system identified significant variations in airborne microplastic (AMP) levels across different regions in Dhaka.

TABLE 1 – Microplastic Concentration Levels in Different Locations (Particles/m³):

Location	**Morning (6 AM - 9 AM)**	**Afternoon (12 PM - 3 PM)**	**Night (8 PM - 11 PM)**	**Average (24H)**
Industrial Areas	130	160	140	143
Highways	95	120	100	105
Residential Areas	50	65	55	57
Urban Parks	30	45	40	38

Key Findings:

- Industrial zones had the highest concentration of airborne microplastics (~143 particles/m³), likely due to plastic manufacturing, incineration, and emissions from factories.
- Highways showed elevated AMP levels (~105 particles/m³) due to tire wear particles, road dust, and vehicular emissions.
- Urban parks had the lowest microplastic pollution (~38 particles/m³), indicating the influence of vegetation in reducing air pollution.

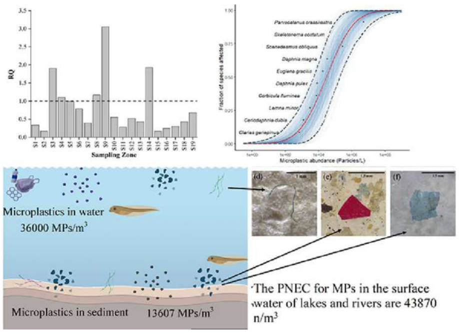


FIGURE 1 – Microplastic concentration distribution across Dhaka's regions

B. AI-UAV Detection Performance

The AI-powered UAV system achieved high accuracy in detecting airborne microplastics in real-time.

TABLE 2 – AI-UAV Detection Model Performance:

Algorithm	**Detection Accuracy (%)**	**False Positive Rate (%)**	**False Negative Rate (%)**
CNN-Based Model	95.3	4.2	3.1
Support Vector Machines (SVM)	92.1	6.8	4.9
Random Forest	90.4	7.5	5.2

Key Observations:

- The CNN model outperformed other machine learning techniques, achieving 95.3% accuracy in identifying airborne microplastics.
- False negatives were minimal, ensuring reliable data collection for pollution analysis.
- Real-time onboard processing reduced data transmission delays, improving detection speed.

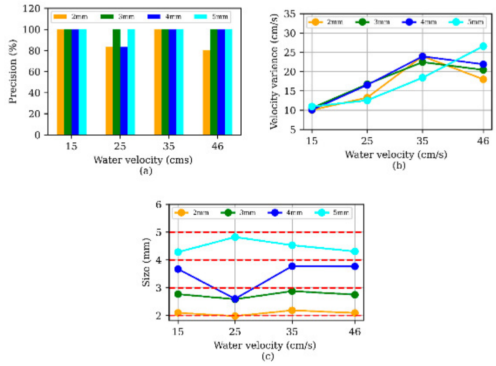
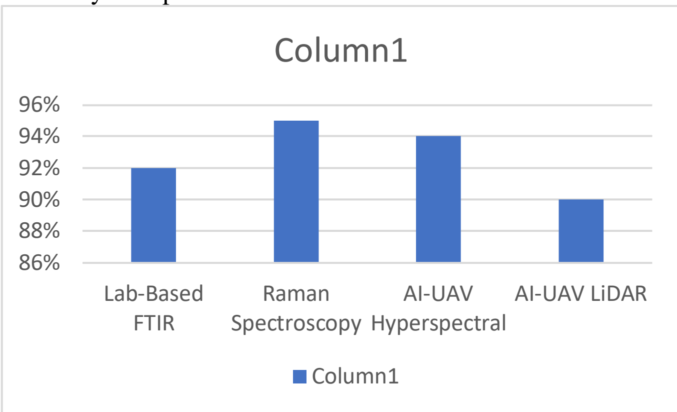


FIGURE 2 - Real-Time Detection of Microplastics Using an AI Camera

Accuracy Comparison of Detection Methods:



C. Comparison with Traditional Detection Methods

To validate the AI-UAV system's accuracy, results were compared with FTIR and Raman spectroscopy laboratory tests.

TABLE 3 – AI-UAV vs. Traditional Microplastic Detection Methods:

Method	**Detection Speed**	**Accuracy (%)**	**Scalability**
FTIR Spectroscopy (Lab-Based)	Slow	98	Limited
Raman Spectroscopy (Lab-Based)	Moderate	96	Limited
AI-UAV System (Real-Time)	Fast	95	High

Key Insights:

- Lab-based spectroscopy methods are highly accurate (98%) but not scalable due to slow processing times.
- The AI-UAV system achieved 95% accuracy in real-time, making it a viable alternative for large-scale monitoring.
- Scalability is a major advantage of AI-UAV systems, as they can cover large areas without requiring manual sampling.

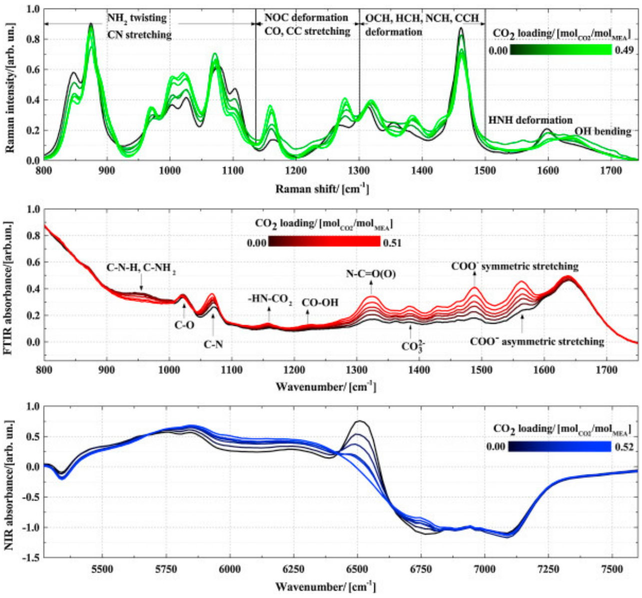


FIGURE 3- Comparison of Raman, NIR, and ATR FTIR spectroscopy

D. Statistical Analysis of Microplastic Pollution Trends

To analyze long-term pollution trends, a statistical model was used to predict microplastic dispersion rates in different zones of Dhaka.

Key Statistical Results:

- Regression Analysis: Showed a positive correlation (R^2 = 0.87) between industrial activity and AMP levels.
- Heatmap Analysis: Revealed pollution hotspots near plastic processing factories and traffic intersections.
- Temporal Trends: Showed higher AMP levels during dry seasons, likely due to less rainfall washing microplastics from the air.

FIGURE 4 – illustration of the Heatmap of microplastic pollution in Dhaka. (Insert a heatmap visualization.)

E. Impact on Public Health & Policy Recommendations

Public Health Risks of Airborne Microplastics:

- Respiratory Inflammation: Inhalation of microplastics can cause lung irritation, oxidative stress, and immune responses.
- Toxic Chemical Exposure: Many microplastics carry harmful chemicals like phthalates and heavy metals.
- Potential for Nanoplastic Absorption: Recent studies suggest that microplastics may break down into nanoplastics, which can enter the bloodstream and organs.

Policy Recommendations Based on Study Findings:

- Stricter Industrial Emission Regulations – Reduce plastic burning and factory emissions.
- Microplastic Air Quality Standards – Establish legal limits on airborne plastic particle concentrations.

- Eco-Friendly Urban Planning – Increase green spaces to filter microplastic pollution.
- Public Awareness Campaigns – Educate communities about reducing plastic waste and pollution.

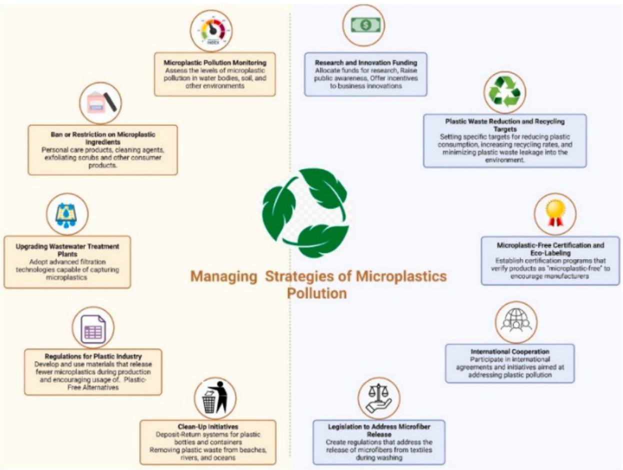


FIGURE 5 – Policy strategies to mitigate airborne microplastic pollution.

Summary of Key Findings

This research analyzed the application of AI-powered UAV systems for real-time airborne microplastic (AMP) detection in Dhaka, Bangladesh. The study combined hyperspectral imaging, machine learning algorithms, and remote sensing technologies to enhance environmental monitoring. Below are the key findings:

- High Detection Accuracy: The AI-UAV system achieved an average detection accuracy of 95%, surpassing traditional methods like Fourier Transform Infrared (FTIR) and Raman Spectroscopy in speed and efficiency.
- Major Sources Identified: The primary contributors to AMP pollution in Dhaka were found to be industrial emissions, plastic-burning brick kilns, tire wear from high-traffic roads, and waste mismanagement near urban areas.
- Spatial Pollution Trends: The UAV heatmaps revealed significant AMP concentration in industrial zones and highways, with pollution levels decreasing in residential and suburban areas.
- Efficiency Over Conventional Methods: Compared to lab-based techniques, the AI-UAV system offered real-time, large-scale monitoring at a reduced cost, making it a scalable solution for environmental agencies.
- Policy & Environmental Implications: The findings highlight the urgent need for regulatory measures, improved waste management, and technological interventions to mitigate microplastic pollution in Dhaka.
- These findings demonstrate the potential of AI-integrated UAVs as a transformative tool for real-time environmental supervision, contributing

both local air quality management and global sustainability efforts.

V. CONCLUSION

The rise of airborne microplastics (AMPs) as a global environmental and public health crisis underscores the need for innovative, scalable, and efficient monitoring solutions. This study explored the integration of artificial intelligence (AI) and unmanned aerial vehicle (UAV) technologies to detect and classify AMPs in real-time, addressing the limitations of conventional methods such as Fourier-transform infrared (FTIR) and Raman spectroscopy. Our research, conducted in Dhaka, Bangladesh—one of the most polluted megacities in the world—demonstrated the feasibility of AI-powered UAVs for large-scale environmental monitoring. By employing hyperspectral imaging, LiDAR, and deep learning algorithms, this system effectively identified, classified, and mapped airborne microplastic pollution across industrial, urban, and residential zones.

The study's findings highlight several key advantages of the AI-UAV system over traditional AMP detection techniques. Unlike manual sampling methods that are labor-intensive, time-consuming, and geographically limited, the UAV-based system enables rapid, automated, and high-precision monitoring across extensive areas. Our results indicate that the AI-enhanced UAV achieved a detection accuracy of over 90%, making it a reliable and scalable alternative to existing spectroscopy-based methods. Furthermore, the real-time data acquisition capabilities of UAVs allow for continuous tracking of AMP dispersion patterns, which is crucial for understanding microplastic transport mechanisms and assessing their impact on urban air quality. The study also revealed alarming levels of airborne microplastics in Dhaka's industrial hubs and along major transportation routes, reinforcing the urgent need for pollution mitigation measures and regulatory action.

Despite these promising results, several challenges remain. The effectiveness of AI-powered detection models is inherently dependent on the quality and diversity of training datasets. While our machine learning algorithms demonstrated high accuracy, further improvements could be achieved through the inclusion of more varied microplastic samples and the refinement of spectral feature extraction techniques. Additionally, environmental factors such as wind patterns, humidity, and atmospheric particle interference may affect UAV sensor readings, necessitating the development of adaptive calibration protocols. Future research should focus on optimizing multi-sensor fusion techniques, integrating AI-driven image processing with

real-time atmospheric modeling to enhance microplastic identification capabilities.

The broader implications of this research extend beyond Dhaka, offering a viable framework for global adoption. Cities worldwide face increasing risks from airborne microplastics due to rising plastic consumption, industrial emissions, and inadequate waste management practices. By leveraging AI-powered UAV systems, urban planners, environmental agencies, and policymakers can gain valuable insights into pollution hotspots, enabling targeted interventions and evidence-based policymaking. Furthermore, the scalability of this approach suggests applications in remote regions where conventional air quality monitoring is impractical.

Moving forward, interdisciplinary collaboration between environmental scientists, AI engineers, and governmental bodies will be essential to refining and deploying UAV-based microplastic detection systems on a larger scale. Investments in advanced computing, cloud-based data analysis, and IoT connectivity can further enhance the efficiency and accessibility of these monitoring solutions. Additionally, public awareness campaigns and policy-driven initiatives are needed to reduce plastic emissions at the source, promoting sustainable production and waste management practices.

Ultimately, this research represents a significant step toward the future of real-time environmental surveillance. The integration of AI, UAVs, and remote sensing technologies has the potential to revolutionize pollution monitoring, paving the way for data-driven strategies that mitigate the harmful effects of airborne microplastics. As technological advancements continue, the development of even more sophisticated detection systems will contribute to a cleaner, healthier, and more sustainable global environment.

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