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Corridor-Wide Surveillance Using Unmanned Aircraft Systems Phase III: Freeway Incident Detection and Management: Part B

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POLICY BRIEF

BACKGROUND AND OBJECTIVES

Increasing traffic incidents and delayed traffic incident detection and verification continue to challenge the efficient management of freeway systems. Traditional incident detection methods, such as fixed Closed Circuit Television (CCTV) cameras and roadside sensors, often require high density deployment for accurate detection and are constrained by their limited spatial coverage and inherent delays in detecting and verifying incidents and hard to monitor incident-induced non-recurrent congestions. In contrast, drones or Unmanned Aerial Vehicles (UAVs) equipped with thermal cameras offer unique advantages, including high mobility, low-visibility operation performance, and enhanced privacy protection by avoiding the capture of identifiable personal information. Recognizing these benefits, the current Phase III project was initiated with the overarching objective of developing a drone-based and AI-powered system for real-time traffic incident detection.

This project was designed with a clear set of objectives that align with the pressing need for advanced incident detection on freeways. The primary aims include the collection of thermal video data under varied traffic conditions, including incidents, recurrent congestion, and normal flow, and the extraction of vehicle trajectories from these videos. By converting these trajectories into a comprehensive image dataset, the research team focused on the development and training of a customized lightweight convolutional neural network (CNN)-based model to accurately extract traffic features and detect incidents. Once incidents were detected, the time periods of the incident scene in the video segment, and the length of incident-induced congestion and its propagation speed among multiple flights were extracted and calculated. Additionally, the project sought to implement a user-friendly web-based Graphical User Interface (GUI) that supports real-time system control, detection results visualization, and historical record review. Together, these objectives establish the foundation for a robust automated system that not only enhances detection accuracy and timeliness but also provides actionable information for Traffic Management Centers (TMCs).

METHODOLOGY

To meet the project’s objectives, a systematic approach to data collection and system development was employed. Drones equipped with thermal cameras were deployed to capture thermal video data along freeway corridors. These drones were programmed to operate at a fixed altitude of 200 feet and a consistent cruising speed of 10 mph, ensuring standardized data collection conditions. The thermal video footage thus obtained formed the primary dataset for the project and provided the basis for subsequent data processing.

The raw thermal videos were first processed using a You Only Look Once (YOLO)-based vehicle detection algorithm that identified vehicles within each frame. In combination with Lucas-Kanade optical flow tracking, the system extracted vehicle trajectories by tracking the center-point coordinates across successive frames. A sliding window technique was employed to convert these trajectories into a series of trajectory images, generated at varying extraction periods of 3, 5, 10, 15, and 20 seconds. This process not only produced a rich dataset that captures the dynamics of traffic flow but also allowed for a detailed examination of the effect of different extraction periods and image modes (monochrome versus color) on incident detection model performance.

The next stage involved developing the customized deep learning model, Traffic Condition Detection Network (TCD-Net), which integrates a multi-scale CNN architecture. The model was augmented with a Convolutional Block Attention Module (CBAM) and a Spatial Pyramid Pooling (SPP) module to enhance feature extraction and spatial representation. The model’s performance was tested across various configurations of extraction periods and image modes. The total length of non-recurrent congestion caused by the incident is derived from the cumulative GPS range of consecutively identified incident segments. The propagation speed is then calculated as the rate of change in congestion length between two consecutive detection flights that reported incident presence.

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Finally, these advanced data processing and machine learning model were integrated into a real-time traffic incident detection system. The system incorporates a comprehensive hardware architecture, combining the drone and remote controller, live deck (or a secondary remote controller), and a GPU-equipped workstation, with a software system combing the drone's thermal camera video streaming application, the incident detection framework and a web-based GUI that enables operators to initiate and terminate detection tasks, monitor live results, and access historical detection data. Field experiments were subsequently conducted on freeway segments in Florida to validate the incident detection accuracy and operational efficacy of the system.

RESEARCH FINDINGS

The experimental results from Phase III of the project underscore the high performance and practical utility of the developed system. The customized TCD-Net model demonstrated superior classification accuracy, achieving approximately 99% accuracy along with the lowest loss when trained with monochrome images and a 20-second trajectory extraction interval on our self-collected dataset. The high accuracy of the model indicates that using a 20-second interval captures a more comprehensive representation of vehicle trajectories and the monochrome image provides enhanced edge contours and structural distribution of vehicle trajectories, thereby enhancing the model's ability to distinguish between incidents, recurrent congestion, and normal traffic flow conditions.

Field experiments conducted on a segment of the Interstate 75 freeway in Tampa, Florida, provided critical validation of the system's real-world incident detection capabilities. In a scenario where a rear-end collision occurred, the system successfully detected the incident approximately 12 minutes earlier than the local TMC, demonstrating its potential for early detection, verification, and severity assessment of the incident and rapid emergency response. Furthermore, the system was able to extract additional incident-related features, including the time period in which the incident appears in the video segment, the length of the incident-induced non-recurrent congestion and its propagation speed. These detailed parameters offer valuable insights that can aid TMCs in efficient situation-awareness and formulating effective incident management strategies to mitigate the impact of incidents. Furthermore, the web-based interactive GUI operated normally as designed to initiate and terminate incident detection tasks, visualize detection results, and review historical detection results during multiple field tests. Collectively, these findings confirm that the integration of drone-based thermal imaging with trajectory-based deep learning techniques provides an efficient and accurate solution for real-time traffic incident detection and management.

POLICY AND PRACTICE RECOMMENDATIONS

In light of the research findings, several important policy and practice recommendations emerge to facilitate the integration of drone-based traffic incident detection system into existing transportation management systems. Firstly, it is recommended that policymakers and transportation authorities consider incorporating drone-based monitoring systems as a complementary tool to traditional traffic surveillance methods. The demonstrated ability of the system to detect incidents earlier and to provide detailed congestion metrics highlights its potential to enhance the operational effectiveness of TMCs.

Furthermore, the establishment of comprehensive data privacy and security guidelines is imperative. Given that the system collects thermal video data, which inherently offers privacy advantages by not capturing identifying details, the development of standardized protocols for data storage, access, and sharing will be essential. Such guidelines should ensure that sensitive information remains protected while maintaining the availability of critical incident data for TMCs.

From a practical standpoint, the success of the TCD-Net model and the drone-based real-time incident detection system indicates that investment in validating the system's performance is warranted. Transportation agencies should prioritize the development and testing of the system to further evaluate the incident detection accuracy across diverse environments. Additionally, comprehensive training programs for drone operators and data analysts must be implemented to ensure optimal performance during field operations. These programs should cover drone piloting, data transmission methodologies, and the operation of incident detection systems within the framework of established regulatory standards.

Lastly, pilot projects and further research initiatives are advised to rigorously assess the economic and operational benefits of deploying drone-based incident detection systems on a larger scale. By fostering collaboration among research institutions, government agencies, and industry stakeholders, these initiatives can facilitate the broader adoption of the drone-based incident detection system. Such collaborative efforts will not only help in standardizing operational procedures but also promote continuous improvement in the prompt detection and efficient management of freeway traffic incidents.

For more information on this project, download the entire report at nicr.usf.edu or contact **nicr@usf.edu**

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