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A Comprehensive Literature Review on Traffic Congestion Detection Methods

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Abstract - This survey paper on Comprehensive Literature Review on Traffic Congestion Detection Methods explores different methodologies of traffic congestion detection including traditional methods such as loop detectors, Global Positioning System (GPS) and vehicle-vehicle communications as well as advanced methods which includes deep neural networks like Convolutional Neural Network (CNN) and different versions of YOLO. The aim is to provide readers with the comprehensive overview of various methods of state-of-the-art traffic congestion detection systems.

Key Words: traffic, congestion, convolutional neural network, deep learning, YOLO , loop detector, GPS.

1.INTRODUCTION

Traffic congestion stands as a persistent and escalating challenge in urban locales, significantly impacting transportation system efficiency and residents' overall quality of life. As cities expand and populations burgeon, the demand for adept congestion detection and management intensifies. Technological progress has paved the way for inventive solutions, capitalizing on diverse data sources and sophisticated algorithms to scrutinize and address traffic congestion.

The deployment of Global Positioning System (GPS) technology emerges as a pivotal factor in contemporary congestion detection. Devices equipped with GPS, such as smartphones and in-car navigation systems, furnish real-time location data for vehicles in transit. This abundance of information allows for the continuous tracking of individual vehicles and comprehensive analysis of traffic flow patterns. By aggregating GPS data from a myriad of vehicles, authorities can gain profound insights into the overall traffic dynamics, pinpoint congestion hotspots, and make well-informed decisions to mitigate traffic bottlenecks. Parallelly, conventional loop detectors play a critical role in congestion detection. Embedded in roadways, loop detectors employ electromagnetic sensors to discern vehicle presence. These detectors collect data on vehicle count, speed, and occupancy, offering supplementary insights alongside GPS data. The integration of loop detector information with GPS data augments the understanding of traffic conditions, facilitating accurate and timely congestion detection.

An emerging technology with substantial potential for congestion detection is Vehicle-to-Vehicle (V2V) communication. V2V communication enables vehicles to directly exchange information, sharing crucial data about their speed, location, and other relevant parameters. This direct communication empowers vehicles to anticipate and respond to evolving traffic conditions, fostering smoother traffic flow and diminishing the likelihood of congestion. As V2V communication becomes increasingly prevalent, the scope for proactive congestion detection and avoidance expands.

Artificial Intelligence (AI) and deep learning techniques have ushered in a revolution in congestion detection, especially through the application of Convolutional Neural Networks (CNNs). Renowned for their prowess in processing visual data, CNNs are adept at analyzing images and videos from traffic cameras. By training CNNs on extensive datasets of traffic scenarios, these systems can learn to identify patterns associated with congestion, such as sluggish traffic, queues, and irregularities. The incorporation of CNNs enhances the precision and efficiency of congestion detection by automating the analysis of visual data captured from diverse vantage points.

A specific object detection algorithm gaining traction in traffic congestion detection is You Only Look Once (YOLO). YOLO processes entire images in a single pass, efficiently detecting and locating multiple objects simultaneously. Within the realm of traffic monitoring, YOLO proves instrumental in identifying vehicles, pedestrians, and other pertinent objects, offering a comprehensive overview of the traffic scene. The swiftness and accuracy of YOLO make it particularly well-suited for real-time applications, facilitating rapid and effective congestion detection.

2. LITERATURE SURVEY OVERVIEW

A. Methods using loop detectors.

[1] Identifying Recurring Bottlenecks on Urban Expressway Using a Fusion Method Based on Loop Detector Data.

Li Tang's paper introduces an innovative strategy for detecting traffic bottlenecks on urban expressways by utilizing loop detector data. The method proposed integrates various collection cycles of loop detector data to enhance the precision and efficiency of bottleneck identification. Through leveraging both large and small cycle data, the algorithm achieves fuzzy positioning using the former and precise positioning using the latter, effectively reducing errors caused by data volatility.

The paper details the algorithmic steps, highlighting the computation of spatial range, duration time, and delay associated with identified bottlenecks. To validate the effectiveness of the proposed algorithm in accurately identifying bottlenecks on urban expressways, a case study is conducted. The main goal of this research is to streamline bottleneck identification on urban expressways, aiming to enhance efficiency and precision by combining loop detector data. The success of this approach relies on the quality of loop detector data; however, the growing availability of diverse traffic data sources like GPS and floating car data suggests broader potential applications for merging multisource data. Although the emphasis is on urban expressways, the suggested method could potentially be applied to other road types equipped with loop detectors.

Dataset:The paper uses data which is available online at http://pems.dot.ca.gov.

According to the paper the accuracy of the model depends on the loop detector quality.

[2] Improved vehicle classification from dual-loop detectors in congested traffic.

This study addresses the limitations of traditional vehicle classification methods using dual loop detectors, particularly in scenarios where the assumption of negligible vehicle acceleration at low speeds becomes invalid. The research focuses on mitigating the impact of unobserved acceleration on measured length classes by establishing uncertainty zones based on effective vehicle length and speed measurements from calibrated dual loop detectors.

The analysis utilizes equations of motion to derive sets of true vehicle lengths, speeds, and accelerations that could result in specific combinations of measured data. The study finds that uncertainty zones capture instances where measured length classes may differ from true length classes due to unobserved acceleration. The proposed method significantly improves classification accuracy, assigning over 98% of vehicles to a single class, particularly beneficial at speeds below 15 mph.

Contrary to conventional beliefs, constant speed boundaries perform well even at low speeds, down to 15 mph, when using the recommended classification method introduced or utilized by Coifman and Cassidy (2002) in their work.. The study emphasizes the importance of well-tuned detectors and suggests real-time performance monitoring for reliable classification. While the uncertainty zone method extends meaningful classification to congested sites, the research acknowledges the need for further exploration to derive universal expressions for uncertainty zone boundaries based on different parameters. Overall, the study provides valuable insights for enhancing the accuracy of length-based vehicle classification in real-world traffic scenarios.

This approach significantly reduces classification errors, especially at low speeds, demonstrating over 98% accuracy in stop-and-go traffic.

B. Method using GPS.

[3] Detection of Traffic Congestion and Incidents from GPS Trace Analysis.

This paper by Eleonora D "Andrea introduces a real-time GPS-based system for detecting traffic congestion and incidents, implemented within a Service Oriented Architecture. The system assigns traffic states to city map road segments based on vehicle speeds, sending users alerts about affected areas, specific traffic states (e.g., incidents, slowed or blocked traffic), and estimated vehicle velocities. The system also demonstrates the ability to recognize various congestion levels based on road usage.

Future directions include integrating the system with dynamic routing services for alternative path suggestions, enhancing confidence through predictive traffic state models incorporating external factors like weather and events. Integration with a tweet-based traffic congestion detection service and incorporation into a comprehensive dashboard offering traffic and incident detection, state prediction, route suggestions, and social network-driven event detection are also envisioned. This multi-faceted approach aims to provide users with a comprehensive and real-time understanding of the traffic landscape, enhancing both efficiency and user experience. The proposed extensions underscore the potential for a holistic and integrated approach to urban mobility management. Utilizing a real-time spatiotemporal analysis of GPS traces without requiring a learning phase, experiments conducted with simulated and real GPS data from Pisa showcase a 91.6% incident detection rate with an average detection time below 7 minutes.

C. Method using vehicle-vehicle communications.

[4] Traffic congestion detection in large-scale scenarios using vehicle-to-vehicle communications.

This paper by Bauza R introduces Cooperative Traffic congestion Detection (CoTEC), a novel distributed technique utilizing Vehicle-to-Vehicle (V2V) communications for the detection and characterization of traffic congestion in next-generation Intelligent Transportation Systems (ITS). CoTEC addresses challenges associated with radio propagation, ensuring accurate traffic density estimation, and accommodates the gradual integration of cooperative vehicular communications into the market. Evaluation in a large-scale highway scenario using the iTETRIS simulation platform demonstrates that CoTEC can effectively and accurately detect congestion conditions, including length and intensity, without relying on infrastructure nodes.

Comparison with V2V and infrastructure-based solutions highlights CoTEC's efficiency and cost-effectiveness for road management authorities in congestion detection and characterization. Ongoing research explores communication mechanisms to disseminate CoTEC's congestion information to approaching vehicles, enabling route modification and alternative path selection to avoid congested areas. Future investigations aim to efficiently integrate V2V-based traffic monitoring with cooperative traffic management strategies, particularly in large-scale scenarios, to assess their impact on road traffic conditions and the ability of cooperative systems to distribute traffic flows effectively. CoTEC and its envisioned extensions represent a promising approach for enhancing traffic management and providing timely information to optimize route planning in dynamic urban environments.

D. Method using Convolution Neural Networks (CNN).

[5] Traffic Congestion Detection: Learning from CCTV Monitoring Images using Convolutional Neural Network

This paper by Jason Kurniawana introduces a Convolutional Neural Network (CNN) for traffic congestion detection through an image classification approach. The methodology involves resizing and converting images to 100x100 grayscale without relying on handcrafted features in preprocessing. Future enhancements aim to refine the CNN architecture and incorporate higher-resolution images to further elevate classification performance.

The envisioned system involves real-time traffic congestion detection using the CNN model on CCTV camera images, with potential integration into map/navigation applications for proactive congestion prevention. The proposed system entails users requesting traffic conditions for specific locations at the current time. The system captures real-time CCTV camera images from the requested location, converts them into smaller grayscale images, and employs the trained CNN model to detect congestion conditions through classification. The system provides feedback to users, indicating whether the location is "jammed" or "not jammed." Integration with navigation applications allows the system to detect multiple congestion points simultaneously, enabling the suggestion of alternative routes to users. The proposed approach showcases the potential for advanced CNN-based systems in real-time traffic monitoring and congestion management.

The CNN achieves an impressive average accuracy of 89.50% on a dataset comprising images captured by CCTV cameras.

E. Methods using You Only Look Once(YOLO).

[6] Traffic Congestion Detection from Camera Images using Deep Convolutional Neural Networks.

This paper by Pranamesh Chakraborty explores the impact of recent advances in machine-vision algorithms and high-performance computing on the accuracy of traffic congestion detection from camera images. Leveraging two deep learning techniques, the traditional DCNN and YOLO models, alongside SVM for comparison, the research achieved significant advancements in image classification accuracy.

To streamline the labeling process and ensure uniformity, nearby Wavetronix sensors were employed for congestion identification, supplemented by manual labeling for testing purposes. The models exhibited robust performance in daytime conditions, with ROC curves demonstrating their sensitivity to varying camera configurations and light conditions. Despite challenges such as congestion regions distant from the camera, single-lane blockages, and glare, the deep models consistently achieved AUCs greater than 0.9, indicating robust performance in challenging conditions.

Real-time implementation using the DCNN algorithm showcased congestion detection, with simple persistence tests applied to reduce false alarms. Future studies are proposed to explore different smoothing techniques and model architectures, aiming to improve overall detection rates and reduce false alarms across a network of cameras. These models hold potential for determining different congestion levels and enhancing the accuracy of traffic state determination, encompassing speed, volume, and occupancy metrics.

The YOLO model demonstrated the highest accuracy at 91.2%, followed closely by DCNN at 90.2%, while SVM achieved an 85% accuracy rate.

[7] An Object Detection System Based on YOLO in

Traffic Scene

This paper by Jing Tao explores the use of YOLO (You Only Look Once), a high-speed object detection algorithm based on a single convolutional neural network (CNN). YOLO distinguishes itself by simultaneously handling classification and object location for multiple objects in an image, sacrificing some precision for exceptional speed compared to other algorithms like R-CNN. The authors propose a modification inspired by Fully Convolutional Networks (FCN) to simplify YOLO's structure, improve computational efficiency, and retain its unique characteristics. The paper introduces an object detection system named OYOLO, which combines YOLO with Region-based Fully Convolutional Networks (R-FCN) to enhance accuracy, particularly in location detection. The combination involves parallel execution of the two algorithms, with overlapping outputs processed using Non-Maximum Suppression (NMS) and average class probabilities.

To address the challenges posed by dimly lit images in traffic scenes, the authors incorporate a pre-processing step involving histogram equalization, significantly improving the system's performance. The training process involves Stochastic Gradient Descent (SGD) with carefully adjusted learning rates, achieving a final model referred to as OYOLO. The results showcase OYOLO's efficiency, outperforming other object detection algorithms in speed while maintaining accuracy. The proposed combination of OYOLO and R-FCN demonstrates improved accuracy over individual algorithms, with additional enhancements through pre-processing for nighttime images.

The system achieves an impressive Mean Average Precision (mAP) of 86.4% on the testing set, underscoring its speed, accuracy, and robustness in traffic scene object detection.

[8] Implementation of YOLOv7 (You Only Look Once v7) Method for Traffic Density Detection

The research by Muhamad Nizam Azmi from the CCTV detection experiments at Simpang 4 Pagesangan led to several significant conclusions and recommendations. Initially, the successful implementation of YOLOv7 and YOLOv7-tiny for real-time vehicle detection using CCTV video data is acknowledged, although potential variations in detection accuracy exist due to factors such as camera quality and non-static camera positions. The accurate interpretation of traffic density through computer vision relies on diverse elements, including camera quality, positioning, and lighting conditions. Hence, precise testing under optimal shooting conditions is imperative for dependable traffic density predictions.

Moreover, the research highlights the consistent superiority of the YOLOv7 model over the YOLOv7-tiny model throughout different times of the day, underscoring its higher average accuracy. To further enhance the YOLOv7 model's detection accuracy, it is suggested to fine-tune it with a dataset tailored to the specific problem. Additionally, the evaluation scope could be expanded by comparing the YOLOv7 model's performance with that of other object detection models. While the study currently contrasts YOLOv7 with YOLOv7-tiny, a more comprehensive assessment involving diverse object detection models could yield insights into the most suitable model for highway object detection applications. These recommendations are aimed at refining and extending the effectiveness of computer vision-based traffic monitoring systems.

3. CONCLUSION

In conclusion, addressing the growing challenge of traffic congestion in urban areas requires innovative approaches for detection and management. The integration of diverse technologies such as GPS, loop detectors, vehicle-to-vehicle communication, and convolutional neural networks (CNNs), particularly the You Only Look Once (YOLO) algorithm, offers promising avenues for real-time congestion detection and mitigation. Literature surveys reveal a range of methodologies, each providing unique insights and capabilities, from fusion methods based on loop detector data to real-time GPS trace analysis and the utilization of V2V communication for large-scale congestion detection. CNN-based approaches, especially those leveraging YOLO, demonstrate high accuracy in identifying congestion patterns from camera images, highlighting their potential for proactive congestion prevention and real-time traffic management. Future research directions emphasize the refinement of algorithms, integration with dynamic routing services, and exploration of cooperative traffic management strategies, showcasing the ongoing evolution of congestion detection systems towards more efficient urban mobility solutions.

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