International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Vision-Based System Design and Implementation for Accident Detection and Analysis

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A B S T R A C T

This study focuses on the autonomous identification and evaluation of traffic events using security camera footage, with the entire system implemented and assessed on the Huawei HiKey970 AI display board. The Motion Interaction Field (MIF) strategy is utilized to detect damaged vehicles by analyzing the interactions of moving objects in the video. The YOLOv5 algorithm is employed to pinpoint the locations of damaged vehicles, while a hierarchical clustering method reconstructs vehicle trajectories to recover their prior paths. A perspective transformation is applied to project vehicle motion onto a vertical plane, facilitating better analysis by traffic specialists. The Unconstrained Finite Impulse Response (UFIR) filter is used to estimate vehicle motion without requiring statistical noise data. By estimating speed and impact points from the vertical view, the system enables effective car crash analysis. The proposed framework demonstrates practical value, accurately identifying vehicle trajectories and minimizing errors when evaluated with accident video clips.

Keywords: *Accident detection, speed estimation, target tracking, unbiased finite impulse response (UFIR) filter, vehicles.*

INTRODUCTION

Over the past few decades, the adoption of traffic monitoring technologies for identifying and evaluating incidents has gained significant attention. Traditionally, crash detection at Traffic Management Centers (TMC) has heavily relied on manual observation. While human monitoring can be effective, it has inherent limitations. Firstly, it is impractical for operators to identify all traffic incidents across an entire city in real time, leading to delayed responses and inadequate assistance for those injured in accidents. Secondly, manual analysis of collision causes is often inaccurate due to the difficulty of extracting precise trajectory and speed data from surveillance footage. These challenges underscore the need for automated systems capable of recognizing and analyzing traffic accidents efficiently.

Vision-based collision detection methods have evolved significantly over the past two decades and can be categorized into three main approaches: traffic flow modeling, vehicle behavior analysis, and vehicle interaction modeling [1]. The first approach uses large datasets to model typical traffic flow patterns, flagging deviations in vehicle trajectories as potential collisions [5]-[7]. However, the scarcity of real-world collision trajectory data limits its effectiveness. The second approach analyzes vehicle motion parameters, such as speed, acceleration, and inter-vehicle distances, to detect accidents [8]-[10]. Despite its potential, this method requires continuous monitoring of all vehicles, and its accuracy in high-density traffic scenarios is often constrained by computational resources. The third approach employs interaction models like the Social Force Model [11] and the Intelligent Driver Model [12] to represent vehicle interactions. While this method relies on extensive training data, its accuracy remains low as it primarily detects collisions based on changes in vehicle speed.

LITERATURE REVIEW

Video Analytics for Surveillance: Theory and Practice Over the last two decades, video analytics has emerged as a rapidly advancing field, defined as the autonomous understanding of events occurring in scenes monitored by multiple cameras. Despite substantial progress, current surveillance systems still lack the capability to analyze complex events autonomously within the camera's field of view. This limitation presents a significant drawback, as the vast amount of video data captured by millions of surveillance cameras worldwide remains unexamined in real time. Consequently, these systems are unable to assist effectively in the prevention or mitigation of accidents, crimes, or terrorist activities, which are critical concerns in modern society. Instead, video feeds are primarily utilized for post-event forensic analysis.

Using the Visual Intervention Influence of Pavement Marking for Rutting Mitigation—Part II: Timing Based on Finite Element Simulation Visual intervention significantly influences driving behavior, enabling redistribution of wheel tracks to reduce concentrated axial stresses and mitigate rutting, as demonstrated in a companion study (Part I). This article proposes a three-stage intervention strategy, where the timing is determined using a finite element-based rutting prediction model. The rutting depth data is fitted segmentally to derive a rate curve for rutting deformation, which informs the intervention timings for various pavement structures. Results indicate that SUPERPAVE pavements require the latest intervention, while AC pavements necessitate earlier intervention. Findings also suggest that stronger resistance to rutting delays the stationary state of deformation, thus deferring intervention. Moreover, the longitudinal slope segment requires earlier intervention compared to flat slope sections of similar pavement types. An optimized intervention cycle is shown to extend asphalt pavement service life by 16–31%.

Synergies of Electric Urban Transport Systems and Distributed Energy Resources in Smart Cities Urban transportation systems and buildings account for the majority of energy consumption within cities. While extensive research has been conducted on these systems, their potential synergies have often been overlooked. This study introduces a linear programming model for optimizing the operation and planning of distributed energy resources (DERs) in residential zones, integrating electric public and private transport systems, including electric vehicles (EVs) and metro systems. The model explores synergies, such as utilizing metro regenerative braking energy stored in EV batteries for subsequent use by trains or the vehicles themselves. Case studies based on data from a Madrid residential area and metro line reveal substantial cost reductions, particularly in power costs for metro systems.

Motion Interaction Field for Accident Detection in Traffic Surveillance Videos This research introduces a novel approach to simulating the interaction of moving objects to detect traffic accidents. Inspired by the motion of water waves caused by objects on the surface, the Motion Interaction Field (MIF) is used to represent object interactions in a Gaussian field form. The symmetric properties of the MIF enable traffic accident detection and localization without requiring complex vehicle tracking. Experimental results demonstrate that the proposed method outperforms existing approaches in both identifying and localizing traffic accidents.

Modeling Scene Activities from Event Relationships and Global Rules This study presents a novel topic model to detect activities in complex surveillance scenes by analyzing the underlying dynamics that govern their occurrence over time. Two critical components are considered: global scene states that define spontaneous activity occurrences and local rules that relate past activities to current ones with temporal delays. These components are integrated using a probabilistic framework with a binary random variable to determine their relevance. A collapsed Gibbs sampling approach is used for efficient parameter inference. Experiments on diverse datasets demonstrate the model's ability to capture scene dynamics at multiple temporal scales, predict sequential activities, and provide a rich interpretation of scene dynamics.

A Markov Clustering Topic Model for Mining Behavior in Videos This study addresses fully automated mining of video footage from public places by introducing a Markov Clustering Topic Model (MCTM). The model enhances traditional Dynamic Bayesian Network models (e.g., HMMs) and Bayesian topic models (e.g., LDA) in terms of accuracy, robustness, and computational efficiency. The MCTM clusters visual events into activities and organizes them into global behaviors while correlating these behaviors across time. Using a collapsed Gibbs sampler for offline training and an online Bayesian inference approximation, the model supports real-time dynamic scene interpretation. Experiments on complex public scenarios highlight the model's capabilities in unsupervised learning of dynamic scene structures, behavior mining, and salient event detection.

A System for Learning Statistical Motion Patterns Analyzing motion patterns offers a powerful means to detect anomalies and predict behavior. Current approaches rely on predefined scenarios where objects follow predictable paths. This study proposes a system for autonomously learning motion patterns to detect anomalies and forecast actions. A fuzzy k-means algorithm groups foreground pixels during object tracking, with cluster centroids representing moving objects. Hierarchical grouping of trajectories based on spatial and temporal features is used to model motion patterns, which are represented as chains of Gaussian distributions. Statistical methods enable anomaly detection and behavior prediction from these learned patterns. The system's performance is validated using sequences from real-world and simulated traffic scenarios, demonstrating robust tracking, efficient pattern learning, and effective anomaly detection.

METHODOLOGY

Autonomous Traffic Accident Identification Framework

Recent advances have introduced several deep learning-based algorithms aimed at autonomous traffic accident detection. These systems leverage complex neural networks and require extensive training data to accurately identify collisions in videos. However, their practical deployment faces significant challenges due to the limited availability of training data and high computational demands. Additionally, the ever-increasing volume of traffic surveillance footage makes it impractical to rely solely on centralised systems for city-wide accident detection and analysis. Instead, a distributed architecture with embedded devices deployed across city blocks is essential for efficient and scalable accident monitoring. Therefore, there is a critical need for a lightweight framework suitable for embedded device deployment.

Challenges

1. Limited training data and high computational costs hinder the practical implementation of these frameworks.
2. Centralised systems struggle to process the growing volume of traffic surveillance footage across an entire city effectively.

Proposed System

This study presents a novel system for traffic accident detection and analysis designed to operate on AI demonstration boards. The framework employs the Motion Interaction Field (MIF) model for rapid identification and localisation of traffic incidents. Vehicle trajectories prior to collisions are reconstructed using a YOLOv3 model combined with hierarchical clustering. To ensure precise event assessment, unbiased finite impulse response (UFIR) filtering and perspective transformation techniques are used to estimate vehicle speed and contact angles during accidents. The system's implementation was validated on the HiKey970 Huawei AI showcase board, demonstrating its feasibility and performance.

Advantages

1. The framework's implementation and efficiency were validated through experiments using the HiKey970 AI demo board, which was used to execute all proposed algorithms.
2. The demo board successfully processed multiple accident surveillance videos, accurately detecting accidents and extracting vehicle trajectories.

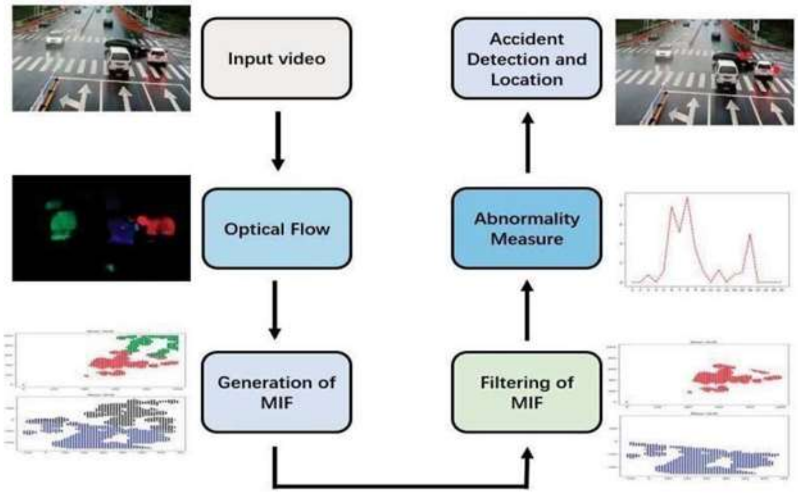


Fig. 1: System Architecture

Modules

To implement the proposed framework, the following modules were developed:

- **Data Ingestion:** Facilitates data input into the system.
- **Data Processing:** Handles preprocessing and feature extraction for the input data.
- **Data Partitioning:** Divides the dataset into training and testing subsets for model evaluation.
- **Model Development:** Implements the YOLOv5 model for efficient object detection.
- **User Management:** Manages user registration and authentication through signup and login functionalities.
- **User Interaction:** Provides an interface for users to input prediction queries.
- **Prediction Output:** Displays the final predictions based on the processed data.

This modular framework enables efficient traffic accident detection and trajectory reconstruction, making it a practical solution for deployment on embedded AI systems.

IMPLEMENTATION

YOLOV5:

YOLO, which stands for "You Only Look Once," is an object identification technique that splits photos into grids. Each grid cell is in charge of detecting items inside itself. Because of its speed and precision, YOLO is one of the most well-known object detection techniques. YOLO (You Only Look Once) models are used for high-performance object identification. YOLO splits a picture into grids, each of which identifies things inside itself. Based on the data streams, they may be utilised for real-time object detection.

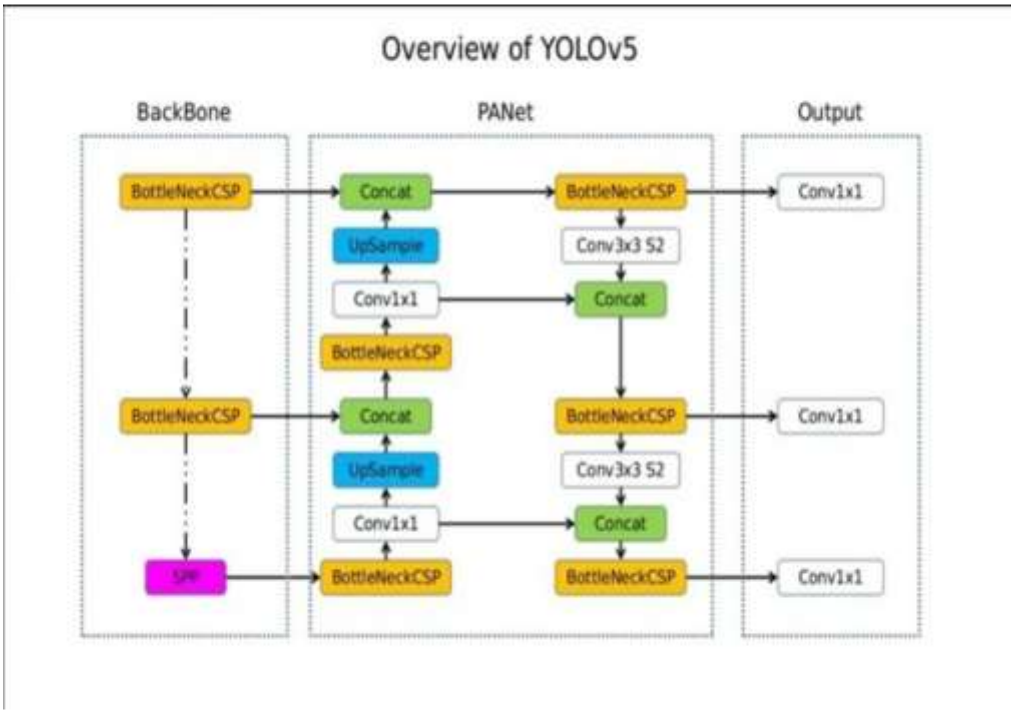
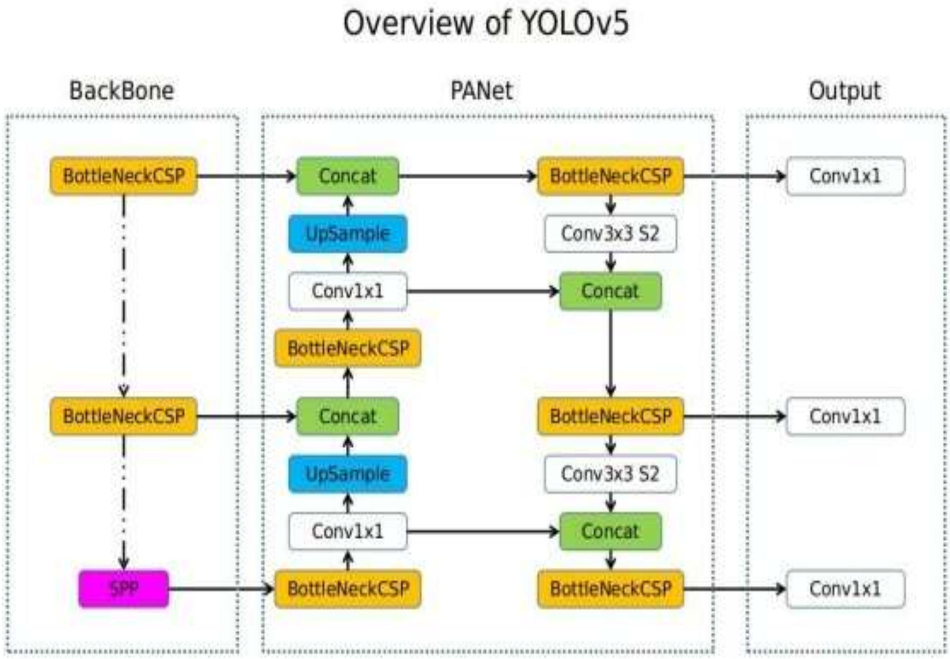


Fig.2 .Flowchart for Backend Design

YOLOv5 architecture

The YOLOv5 architecture is structured as a convolutional neural network (CNN) and consists of three primary components: the Backbone, Neck, and Head. The Backbone utilizes Cross Stage Partial Network (CSPNet) to extract key features from the input images. The Neck is responsible for generating a feature pyramid, which facilitates the detection of objects at different scales. These components work in unison to enhance the efficiency and accuracy of the object detection process.



5. CONCLUSION

This study proposes an automated methodology for detecting and analyzing traffic accidents using surveillance video. Initially, the Motion Interaction Field (MIF) model was applied to identify and localize accidents within the video frames. Following this, the YOLO v3 model was employed for the precise detection of damaged vehicles. The hierarchical clustering technique was then utilized to reconstruct vehicle trajectories prior to the collision. To assist traffic authorities in decision-making, the reconstructed trajectories were transformed into a vertical perspective using a perspective transformation. Unbiased Finite Impulse Response (UFIR) filtering was applied to refine the trajectories, enabling accurate determination of vehicle velocity. The estimated velocity, combined with the impact angle derived from the vertical perspective, was used to evaluate the accident's dynamics. Finally, the proposed framework was implemented on the HiKey970, a Huawei AI demo board, for hardware validation. Accident surveillance videos were used as input for testing. The system successfully detected accidents and retrieved the corresponding vehicle trajectories. Performance evaluation demonstrated that HiKey970 outperformed an Intel Core i7-9750H CPU @ 2.60 GHz by achieving a speed improvement ranging from 28.85% to 45.72%.

6. FUTURE WORK

There are several challenges that warrant further exploration. First, alternative deep learning models could be investigated to enhance recognition accuracy, particularly in scenarios where vehicles are partially or fully obstructed. Second, advanced image enhancement techniques could be incorporated to improve the effectiveness of accident detection under varying weather conditions or when surveillance footage quality is suboptimal. Third, incorporating license plate recognition for vehicles involved in collisions could facilitate more detailed post-incident investigations. Future research will also focus on developing robust trajectory tracking and intrusion detection mechanisms for autonomous vehicles, ensuring greater safety and reliability in intelligent transportation systems.

7. REFERENCES

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