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A Systematic Review of Stop Line and Zebra Crossing Detection Techniques

Dipak Agrawal [1], Dr. Amit Nayak*[2], Amit Chaudhari [3], Pravin Jadav [4]

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Abstract: This systematic review critically examines and synthesizes the existing literature on stop line and zebra crossing detection techniques, with a focus on enhancing road safety and supporting the visually impaired. The survey encompasses a range of methodologies, including computer vision, image processing, and deep learning, to address the challenges associated with accurate identification and recognition of these critical road elements. Key topics explored include the utilization of Hough transform, curve modeling, flood fill operations, uniform local binary pattern detection, and convolutional neural networks. The review assesses the strengths, limitations, and comparative performance of each technique, highlighting innovations such as adaptive histogram equalization, morphological operations, and regression approaches. The outcomes of this review contribute to a comprehensive understanding of current advancements and pave the way for future research directions in the domain of intelligent transportation systems and assistive technologies for pedestrians, particularly the visually impaired.

Keywords: *Intelligent vehicle, Road environment recognition, Computer vision*

1. Introduction

Road safety and efficient traffic management are paramount concerns in modern transportation systems. Stop lines and zebra crossings play pivotal roles in regulating traffic flow, ensuring pedestrian safety, and facilitating the smooth operation of vehicular movement. Accurate detection of these road markings is essential for the development of intelligent transportation systems (ITS) and automated driving technologies. In recent years, significant advancements have been made in the field of computer vision, machine learning, and image processing, leading to the development of sophisticated techniques for detecting stop lines and zebra crossings.

The detection of stop lines, typically marked at intersections and pedestrian crossings, is crucial for enforcing traffic rules, preventing accidents, and optimizing traffic flow. Traditional methods of stop line detection have primarily relied on edge detection algorithms, Hough transforms, and geometric pattern recognition. However, challenges arise when stop lines are faded, damaged, or obscured by environmental factors such as shadows and adverse weather conditions. Addressing these challenges requires innovative approaches that are robust, reliable, and adaptable to diverse real-world scenarios.

Similarly, the accurate detection of zebra crossings is essential for ensuring the safety of pedestrians, especially those with visual impairments. Zebra crossings provide designated pathways for pedestrians to cross roads safely and are marked by distinctive patterns of parallel white lines. Detecting zebra crossings in real-time poses significant challenges due to variations in lighting conditions, occlusions, and the complexity of urban environments. As such, there is a growing need for advanced computer vision techniques capable of robustly identifying zebra crossings under varying conditions.

This systematic review aims to comprehensively evaluate existing stop line and zebra crossing detection techniques reported in the literature. By synthesizing insights from a diverse range of research papers, this review seeks to identify key methodologies, algorithms, and technological innovations employed in stop line and zebra crossing detection. Furthermore, the review aims to analyze the strengths, limitations, and performance metrics of different detection techniques, thereby providing valuable insights for researchers, practitioners, and stakeholders involved in transportation engineering, urban planning, and intelligent mobility systems.

The systematic review will follow a structured

[1] *PhD research scholar, Department of Computer Engineering, CSPIT,CHARUSAT Campus, Highway, Off, Nadiad - Petlad Rd, Changa, Gujarat 388421*
Email:- 22DRCE001@charusat.edu.in
ORCID ID : 0009-0004-7711-8880
[2] *Associate Professor, Department of Information Technology, DEPSTAR,CHARUSAT Campus, Highway, Off, Nadiad - Petlad Rd, Changa, Gujarat 388421*
**Email:-Amitnayak.it@charusat.ac.in*
ORCID ID : 0000-0022-0439-4946
[3] *Assistant Professor,Department of Information Technology, SVIT, Vasad Anand, Gujarat 388306*
Email:-amit16.chaudhari@yahoo.in
[4] *Assistant Professor,Department of Information Technology, SVIT,Vasad Anand, Gujarat 388306*
Email:-pravin.jadav17@gmail.com

methodology, including comprehensive literature search, selection criteria, data extraction, and synthesis of findings. Emphasis will be placed on identifying emerging trends, challenges, and future research directions in the field of stop line and zebra crossing detection. The findings of this review are expected to contribute to the advancement of ITS technologies, improve road safety, and enhance the accessibility of urban environments for all road users.

This systematic review represents a critical examination of stop line and zebra crossing detection techniques, aiming to provide a comprehensive understanding of current methodologies and insights for future research and development in the field of transportation and urban mobility.

This systematic review endeavors to provide a comprehensive overview of stop line and zebra crossing detection techniques, elucidating their strengths, limitations, and potential applications in intelligent transportation systems. By synthesizing insights from diverse research papers, this review aims to inform future research directions and facilitate the development of robust and reliable detection systems for enhanced road safety and traffic management.

2. The Need for Stop Line and Zebra Crossing Detection

The need for stop line and zebra crossing detection arises from several critical factors related to road safety, traffic management, and the effective functioning of transportation systems:

Enhancing Road Safety: Stop lines and zebra crossings are fundamental elements of road infrastructure designed to promote safety for both motorists and pedestrians. Detecting these markings accurately is crucial for ensuring compliance with traffic regulations, preventing accidents, and reducing the risk of collisions at intersections and pedestrian crossings.

Regulating Traffic Flow: Stop lines play a pivotal role in regulating the flow of vehicular traffic at intersections and junctions. Detecting stop lines allows automated systems to recognize designated stopping points, facilitating the orderly movement of vehicles and minimizing traffic congestion.

Pedestrian Safety: Zebra crossings provide designated areas for pedestrians to cross roads safely. Accurate detection of zebra crossings enables intelligent transportation systems to prioritize pedestrian safety by signaling to motorists the presence of pedestrian crossing zones and encouraging compliance with traffic regulations.

Enabling Intelligent Transportation Systems (ITS): The integration of advanced detection techniques for stop lines and zebra crossings is essential for the development and deployment of intelligent transportation systems. These systems leverage technology to enhance traffic efficiency, reduce environmental impact, and improve overall road safety.

Supporting Vulnerable Road Users: Detecting zebra crossings is particularly crucial for supporting vulnerable road users, such as visually impaired individuals. Accurate identification of zebra crossings allows for the implementation of auditory and tactile signaling systems, aiding visually impaired pedestrians in navigating road crossings safely.

Compliance Enforcement: Automated detection of stop line violations and unauthorized use of zebra crossings enables enforcement agencies to monitor and deter traffic infractions effectively. By deploying detection systems, authorities can identify instances of non-compliance, issue citations, and promote adherence to traffic regulations.

Facilitating Urban Mobility: In densely populated urban environments, efficient detection of stop lines and zebra crossings is essential for facilitating smooth traffic flow and enhancing overall mobility. Accurate detection enables adaptive traffic signal control systems to optimize signal timing, minimize delays, and improve the efficiency of urban transportation networks.

3. Research approach

The research approach discussed in the seven papers explores innovative methods and technologies for enhancing road safety and autonomous vehicle control. The first paper delves into the detection of damaged stop lines by focusing on the distribution of paired edges, while the second paper proposes a reevaluation of efficient lane detection through curve modeling. The fourth study deals with stop sign and stop line detection coupled with distance computation for autonomous vehicle management, while the third paper investigates the use of the Hough Transform for stop line violations. Furthermore, the sixth study suggests zebra-crossing detection and recognition based on flood fill operation and uniform local binary pattern, while the fifth paper presents a block-based Hough Transform for zebra-crossing recognition in photos of natural scenes. Finally, a convolutional neural network-based regression method for zebra crossing detection is presented in the seventh paper. In an effort to increase road safety and efficiency, these research projects work together to advance the fields of computer vision and intelligent transportation systems.

3.1. Detection of Damaged Stop Lines on Public Roads by Focusing on Piece Distribution of Paired Edges [2]

3.1.1. Problem Definition: Define the problem of detecting damaged stop lines on public roads, emphasizing the limitations of existing methods in rural areas due to damaged paint and the absence of lane marks.

3.1.2. Image Preprocessing: a. Inverse Perspective Mapping: Apply inverse perspective mapping to the camera input image to create a transformed image. b. Edge Extraction: Utilize a Sobel filter to extract positive and negative edges from the transformed image.

3.1.3. Edge Pair Verification: Confirm pairs of positive and negative edges by analyzing the width between them in the trinarized edge image.

3.1.4. Stop Line Candidate Detection: a. Hough Transformation: Apply the Hough transformation to identify line segments in the trinarized edge image. b. Distribution Analysis: Analyze the distribution of line segments to detect candidates for damaged stop lines.

3.1.5. Integration with Driving Data: a. Driving Distance Estimation: Incorporate data on estimated driving distance to enhance stop line detection. b. Preceding Vehicle Detection: Integrate results from the detection of preceding vehicles to prevent false positives in bicycle crossing lanes and account for potential obstacles.

3.1.6. Performance Evaluation: a. Data Collection: Collect driving data on actual public roads, including scenarios with damaged stop lines and various environmental conditions. b. Offline Evaluation: Evaluate the proposed system offline using collected data to assess its ability to detect target stop lines without false detections. Measure detection speed and accuracy.

3.2. The Rethinking Efficient Lane Detection via Curve Modeling[1]

3.2.1. Problem Definition: Clearly define the problem of lane detection in RGB images and highlight the limitations of existing segmentation-based and point detection-based methods that require heuristics or anchor formulations. Emphasize the need for a novel parametric curve-based approach.

3.2.2. Curve-Based Lane Detection Framework: a. Parametric Bézier Curve: Introduce the use of parametric Bézier curves for lane representation, justifying its selection based on ease of computation, stability, and high degrees of freedom for transformations. b. Optimization Enhancement: Address optimization difficulties associated with existing polynomial curve methods and demonstrate how the proposed Bézier curve method overcomes these challenges.

3.2.3. Feature Fusion Technique: a. Deformable Convolution: Introduce the deformable convolution-based feature flip fusion technique for exploiting symmetry properties of lanes in driving scenes. b. Symmetry Exploitation: Explain how the proposed feature fusion technique enhances the model's ability to capture symmetric lane structures, improving overall detection accuracy.

3.2.4. Performance Evaluation: a. Benchmark Datasets: Utilize popular benchmark datasets, such as LLAMAS, TuSimple, and CULane, to evaluate the proposed method's performance. b. Metrics: Define appropriate evaluation metrics, considering accuracy, latency, and model size, to assess the method's efficiency and effectiveness. c. Comparison with State-of-the-Art: Compare the proposed method's performance with state-of-the-art lane detection methods to showcase its superiority.

3.2.5. Implementation Details: a. Framework and Tools: Specify the programming framework and tools used for implementing the proposed method. b. Training Process: Describe the training process, including data preprocessing, augmentation, and hyperparameter tuning.

3.2.6. Experimental Results Analysis: Analyze the results obtained from the experiments, discussing the achieved state-of-the-art performance on LLAMAS and favorable accuracy on TuSimple and CULane datasets. Highlight the significance of the proposed method in terms of both performance and computational efficiency.

3.2.7. Discussion on Low Latency and Model Size: Discuss how the proposed method achieves low latency (>150 FPS) and a small model size (<10M), addressing the practical considerations of real-time applications and resource constraints.

3.2.8. Baseline Establishment: Position the proposed method as a new baseline for lane detection, providing insights into the potential of parametric curves modeling for future research in the field.

3.3. Detection of Stop Line Violations Using the Hough Transform[6]

3.3.1. Problem Statement: Clearly define the problem of stop line violations, emphasizing the importance of road user compliance with markings for traffic safety. Highlight the specific issue of violations before pedestrian crossings and the need for an automated detection system.

3.3.2. Objective Definition: Clearly state the objective of the research: to develop an automatic detection system for stop line violations using the Hough transform.

3.3.3. Hough Transform Overview: Provide a detailed explanation of the Hough transform, emphasizing its suitability for line detection in images and its potential application to identifying stop line violations.

3.3.4. Dataset Collection: a. Morning, Afternoon, and Evening Data: Collect datasets representing different times of the day to assess the system's performance under varying lighting conditions. b. Pedestrian Crossing Scenarios: Ensure the dataset includes scenarios with stop line violations specifically before pedestrian crossings.

3.3.5. Experimental Setup: a. Parameters Selection: Define the parameters for the Hough transform, considering both the default set and an alternative set for comparison. b. System Configuration: Specify the hardware and software configurations used for the experiments.

3.3.6. Algorithm Implementation: a. Hough Transform Integration: Integrate the Hough transform into the detection algorithm, ensuring it can effectively identify stop line violations in the given scenarios. b. Image Preprocessing: Implement any necessary preprocessing steps to enhance the quality of input images.

3.3.7. Performance Evaluation: a. Accuracy Metrics: Define accuracy metrics for evaluating the system's performance, considering true positives, false positives, and false negatives. b. Time Analysis: Assess the computational efficiency of the system, particularly its ability to process images in real-time.

3.3.8. Results Analysis: a. Morning, Afternoon, and Evening Performance: Analyze the accuracy rates for different datasets based on the time of day. b. Effect of Lighting and Stop Line Quality: Investigate the impact of lighting conditions and stop line quality on the system's performance.

3.4. Stop Sign and Stop Line Detection and Distance Calculation for Autonomous Vehicle control

3.4.1. Problem Definition: Clearly define the problem of stop sign and stop line detection for autonomous vehicle control. Emphasize the importance of environmental perception in autonomous driving and the need to follow traffic rules for safe vehicle speed control.

3.4.2. Stop Sign Detection: a. Feature Types: Investigate and compare three different feature types - Haar-like features, Local Binary Patterns (LBP), and Histogram of Oriented Gradients (HOG) - for stop sign detection using AdaBoost cascade classification. b. Classifier Comparison: Analyze and compare the performance results of the three classifiers to determine which one is most effective for stop sign detection under various conditions.

3.4.3. Stop Line Detection: a. Computer Vision Algorithm: Propose a classic computer vision algorithm for stop line detection, considering the challenges posed by varying lighting conditions and the quality of road markings. b. Real-Time Implementation: Optimize the algorithm for real-time processing, ensuring that the stop line can be detected efficiently as the vehicle approaches.

3.4.4. Distance Calculation: a. Real-Time Estimation: Develop a method for real-time estimation of the distance to the stop sign and stop line using information obtained from the detected features. b. Integration with Control System: Integrate the distance information into the autonomous vehicle control system to enable the application of decelerating torque for safe and precise stopping.

3.4.5. Experimental Setup: a. Dataset: Collect a diverse dataset containing various scenarios, lighting conditions, and road markings to evaluate the robustness of the proposed method. b. Performance Metrics: Define appropriate performance metrics, such as accuracy, precision, and recall, to assess the effectiveness of stop sign and stop line detection, as well as the accuracy of distance estimation.

3.4.6. Analysis and Comparison: Evaluate the results of the experiments and compare the performance of the proposed stop sign and stop line detection system with existing methods or benchmarks. Analyze the strengths and weaknesses of the system under different conditions.

3.4.7. Real-Time Testing: Conduct real-time testing to validate the feasibility and efficiency of the proposed method in a controlled environment and, if possible, in real-world scenarios.

3.5. Block-based Hough Transform for Recognition of Zebra Crossing in Natural Scene Images[4]

3.5.1. Problem Definition: Clearly define the problem of recognizing zebra crossings in natural scene images and highlight the challenges associated with variations in lighting, shadows, and perspective distortions.

3.5.2. Block-Based Hough Transform: a. Block Layout: Define the approach of laying overlapping blocks on the region of interest (ROI) in each image for efficient zebra crossing recognition. b. Patch Processing: Detail the two-step process for each patch within the block - edge detection using preprocessing and parallel lines detection using the Hough transform.

3.5.3. Preprocessing: a. Edge Detection: Specify the edge detection technique used in the preprocessing step, highlighting its effectiveness in minimizing the impact of shadows. b. Adaptive Thresholding: Explain the use of adaptive thresholding to enhance the accuracy of edge detection across various lighting conditions.

3.5.4. Parallel Lines Detection: a. Hough Transform: Explain how the Hough transform is employed for the detection of straight lines in each patch within the block. b. Angle Averaging: Describe the process of averaging the angles of parallel lines detected to determine the direction of the zebra crossing.

3.5.5. Position Synthesis: a. Accumulative Scores: Detail how accumulative scores from all processed blocks are synthesized to provide the final position of the zebra crossing. b. Directional Information: Discuss how the averaged angles contribute to providing directional information about the zebra crossing.

3.5.6. Performance Evaluation: a. Dataset: Collect a diverse dataset of natural scene images containing zebra crossings under different conditions for evaluating the proposed method. b. Evaluation Metrics: Define appropriate evaluation metrics, such as accuracy, precision, and recall, to assess the performance of the block-based Hough transform method.

3.5.7. Comparative Analysis: Compare the proposed block-based Hough transform method with existing approaches or benchmarks, emphasizing the advantages and improvements achieved.

3.5.8. Robustness Testing: Conduct robustness testing to assess the performance of the method under varying lighting conditions, shadows, and perspective distortions.

3.6. Zebra-Crossing Detection and Recognition Based on Flood Fill Operation and Uniform Local Binary Pattern[7]

3.6.1. 1. Problem Definition: Clearly define the problem of zebra-crossing detection and recognition, emphasizing the importance of supporting visually impaired individuals in navigating street crossings safely.

3.6.2. 3. **Image Preprocessing:** a. Adaptive Histogram Equalization: Detail the use of adaptive histogram equalization to enhance the contrast and sharpness of the zebra crossing image. b. Thresholding: Establish an empirical threshold value for intensity, and describe the thresholding process to improve image quality.

3.6.3. Binary Image Conversion: Apply Otsu's method to convert the pre-processed zebra-crossing image into a binary image.

3.6.4. Morphological and Flood Fill Operations: a. Morphological Operations: Describe the application of morphological operations on the binary image to refine and extract the largest candidate object. b. Flood Fill Operation: Explain how the flood fill operation is employed to further delineate the zebra-crossing region.

3.6.5. Edge Detection: Utilize the Canny operator to detect edges in the processed image, preparing it for subsequent analysis.

3.6.6. Horizontal Edge Estimation: a. Elimination of Vertical Edges: Employ the four-connected method to eliminate vertical edges, focusing on potential longest horizontal edges. b. Statistical Threshold Procedure: Apply a statistical threshold procedure to filter out small edges, refining the estimation of potential longest horizontal edges.

3.6.7. Hough Transform: Employ the Hough transform to draw lines and justify potential parallel horizontal edges as zebra-crossing edge lines.

3.6.8. Region of Interest (ROI) Detection: a. Hough Lines Analysis: Analyze the Hough lines to detect the zebra-crossing region of interest (ROI). b. ROI Extraction: Extract the detected ROI for further analysis.

3.6.9. Recognition with SVM Classifier: Apply a support vector machine (SVM) classifier to recognize the zebra-crossing region within the detected ROI.

3.6.10. Feature Extraction: a. Uniform Local Binary Pattern (LBP): Describe the use of rotational invariant uniform local binary pattern to extract features from the candidate region for SVM classification.

3.6.11. Simulation and Results: a. Dataset: Utilize a diverse dataset of zebra-crossing images to simulate and evaluate the proposed method. b. Performance Metrics: Define appropriate performance metrics, such as accuracy, precision, and recall, to assess the effectiveness and superiority of the proposed method.

3.7. regression approach to zebra crossing detection based on convolutional neural networks[5]

3.7.1. Problem Definition: Clearly define the problem of zebra crossing detection, emphasizing the significance of electronic travel aids in locating and estimating the direction of zebra crossings to assist visually impaired individuals in crossing roads safely.

3.7.2. Regression Approach with CNNs: a. Sliding Window Technique: Describe the use of a fixed-size window sliding across the captured image at intersections, providing a localized analysis for zebra crossing detection. b. Logistic Regression Model: Explain how image patches are sequentially fed into a logistic regression model for zebra crossing identification within the sliding window.

3.7.3. Direction Prediction: a. Regression Model: Detail the regression model used for predicting the direction of the identified zebra crossing within the image patch. b. Backpropagation Algorithm: Describe the backpropagation algorithm used to optimize the parameters of the logistic regression and regression models before making predictions.

3.7.4. Performance Metrics: Define appropriate performance metrics, such as precision-recall performance for zebra crossing identification and root mean square error for predicted directions, to quantitatively evaluate the proposed regression approach.

3.7.5. Dataset Collection: a. Diverse Scenarios: Collect a diverse dataset of images captured at intersections, including various lighting conditions, road types, and zebra crossing appearances. b. Ground Truth Annotations: Annotate the dataset with ground truth information regarding the presence and direction of zebra crossings to facilitate model training and evaluation.

3.7.6. Model Training: a. Data Preprocessing: Preprocess the dataset by applying necessary transformations, normalization, or augmentation to enhance model generalization. b. Training Protocol: Develop a training protocol for the logistic regression and regression models, utilizing the annotated dataset to optimize model parameters.

3.7.7. Evaluation and Comparison: a. Baseline Comparison: Compare the proposed regression approach with existing methods, emphasizing improvements in precision-recall performance and reduction in root mean square error. b. Cross-Validation: Implement cross-validation techniques to assess the robustness and generalization ability of the trained models.

4. Conclusion

4.1. conclusion

This systematic review comprehensively explores contemporary research in stop line and zebra crossing detection, emphasizing road safety and aiding the visually impaired. The amalgamation of methodologies, from traditional computer vision to advanced deep learning, underscores the multifaceted approach researchers adopt to address challenges in accurately identifying crucial road elements. The diverse research papers reveal innovative methods, such as leveraging inverse perspective mapping and Sobel filtering for detecting damaged stop lines, introducing parametric Bézier curves for efficient lane detection, and employing the Hough transform for automatic stop line violation detection. These studies showcase practical considerations, including lighting conditions and stop line marking quality, contributing to the field's robustness. The integration of cutting-edge technologies and practical insights in these studies lays the groundwork for future advancements in intelligent transportation systems and assistive technologies, particularly benefitting pedestrians, especially the visually impaired. The synthesized findings underscore the potential for impactful enhancements in road safety and accessibility.

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4.3. Author contributions

Dipak Agrawal: Conceptualization, methodology, literature review, data curation, and analysis.

Dr.Amit Nayak: Investigation, validation, visualization, and writing.

Amit Chaudhari: Visualization, Investigation, Writing-Reviewing and Editing.

Pravin Jadav: Investigation, Writing-Reviewing and Editing.

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