Video-based Assessment Methods for Traffic Safety Conditions on Urban Road Sections: A Postprint

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Abstract

Real-time assessment of urban road traffic safety state constitutes an important research focus in intelligent transportation systems. To address the problem of unsatisfactory evaluation effectiveness of existing real-time traffic safety state assessment methods, this study establishes an assessment method for urban road segment traffic safety state based on video information. First, a rapid detection method for traffic flow parameters using video information is analyzed. Then, from the perspective of speed dispersion, the concept of road segment speed dispersion that influences urban road segment traffic safety state is proposed. Finally, an assessment method for urban road segment traffic safety state based on road segment speed dispersion is established. Experimental results demonstrate that the proposed method can reasonably evaluate the safety state level of urban roads in real time, and the assessment results can provide a corresponding basis for traffic management departments to formulate effective improvement plans for urban road segment traffic safety.

Full Text

Preamble

Safety State Evaluation Method of Urban Road Traffic Based on Video Information

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Abstract: Real-time safety state evaluation of urban road traffic constitutes an important research focus in intelligent transportation systems. To address the unsatisfactory performance of existing traffic safety state real-time evaluation methods, this paper proposes a safety state evaluation method for urban road segments based on video information. First, we analyze rapid detection methods for traffic flow parameters using video information. Then, we introduce the concept of road segment speed dispersion from the perspective of vehicle speed variability. Finally, we establish an urban road segment safety state evaluation method based on road segment speed dispersion. Experimental results demonstrate that the proposed method can evaluate urban road safety state levels in real time and in a reasonable manner, providing a basis for traffic management departments to develop effective urban road traffic safety improvement programs.

Keywords: intelligent transportation system; road safety; video information; vehicle velocity dispersion

0 Introduction

With the rapid development and deployment of Intelligent Transportation Systems (ITS), real-time acquisition of traffic flow parameters through video information has become the primary means of data collection. As a critical research component of ITS, utilizing video information for real-time road safety state evaluation represents an effective approach to improving urban road traffic safety and has attracted widespread attention from scholars both domestically and internationally [1~4]. Reference [5] analyzed the influence mechanism of average speed and speed standard deviation on segment accident rates, revealing that the correlation coefficient between segment accident rates and speed dispersion is the highest. Reference [6] constructed a regional road traffic safety evaluation index system using the grey relational characteristic vector method and grey relational analysis, and determined the corresponding index weights. Reference [7] established an accident probability density function using kernel density estimation and, considering the influence of accident location characteristics and historical data, proposed a safety state evaluation model based on the empirical Bayes method. Reference [8] employed the Analytic Hierarchy Process to investigate the problems of insufficient information and short decision time in road traffic safety evaluation. Although these evaluation methods can assess traffic safety states, they fail to adequately meet the real-time performance and accuracy requirements of ITS.

To address the limitations of existing methods, this paper proposes a novel evaluation approach for urban road segment traffic safety states. First, through rapid detection and recognition of video traffic information, we identify vehicle-related factors affecting traffic safety from the vehicle perspective itself. Then, through analysis of these safety-influencing factors, we introduce the concept of road segment speed dispersion that affects urban road segment traffic safety, approached from the angle of speed variability. Finally, we establish an urban road segment traffic safety state evaluation method based on road segment speed dispersion and validate the proposed method through experiments.

1 Video-Based Traffic Parameter Detection Methods

The application of surveillance cameras has become increasingly widespread and common in modern intelligent transportation. Through extraction and analysis of video information, we can qualitatively and quantitatively obtain traffic operation safety states. Urban roads are typically equipped with surveillance cameras, enabling us to acquire traffic flow parameters (traffic volume and speed) and other road traffic information at intersections through rapid video-based traffic information detection and recognition.

Video-based traffic information rapid detection and recognition centers on machine vision technology [9-10], focusing on automatic detection of road traffic parameters and automatic identification of traffic emergencies through video. By developing traffic video detection and intelligent recognition of traffic conditions in complex scenes, we can solve the problem of rapid and accurate detection of traffic information parameters and traffic emergencies in complex environments.

1.1 Video-Based Road Segment Speed Detection

For urban road traffic, traffic flow parameters mainly include vehicle speeds entering intersections. Video-based speed detection involves issues such as moving target detection and tracking in video sequences. Moving target detection identifies interesting moving targets from video image sequences, which forms the foundation of intelligent vision. Any research on moving target motion characteristics is predicated on moving target detection.

When a moving target passes through a designated detection zone, the displacement is d. The speed detection process is illustrated in Figure 2 [Figure 2: see original paper]. Using this method, we can obtain speed information simply, quickly, and without sacrificing accuracy.

Common moving target detection methods include the background difference method and motion analysis-based methods. The core of the background difference method is background modeling, which determines whether a point belongs to the foreground or background by comparing the image with a background model. Common background modeling methods include the single Gaussian model. Stauffer et al. proposed a modeling method using a mixture of Gaussian models [11]. Motion analysis-based methods mainly include optical flow method and inter-frame difference method [12]. Based on motion analysis methods, we can calculate vehicle speed according to the displacement difference of vehicles in two consecutive frame images.

We delineate a detection zone in the image. When a vehicle enters this zone at time t , we record the current frame image. At time t when the vehicle is about to leave the red detection zone, we record that frame image. The time spent passing through the red zone is Δt = t - t . Based on a simple camera calibration method, since our objective is to obtain the vehicle' s actual speed rather than its pixel movement speed in the image, the speed unit should be km/h rather than pixels/time. Therefore, we must establish the relationship between pixel movement and actual distance.

Figure 1 [Figure 1: see original paper] shows a side schematic diagram of a vehicle passing between two consecutive frames in a typical road surveillance camera. In road traffic systems, the camera' s shooting depression angle is generally no less than 60°, the viewing distance c, and the distance y between the detection point and the camera are generally large. When the angle is small, it becomes very small compared to y. When ignoring changes in the shooting depression angle in the diagram and considering only the perspective generated by , we assume that all points in the detection zone maintain a constant elevation angle to the camera.

The width of the detection zone delineated in the image is exactly one lane width (in China' s multi-lane highways above class III, the motor vehicle lane width is approximately 3.5 m). Therefore, based on the actual pixel size of the delineated zone, we can conveniently determine the vehicle' s displacement through the detection zone.

Let the actual road distance corresponding to the detection zone in the vertical direction be d meters. Since we previously set that visual perspective effects are not considered, we can assume that equal vertical distances in the image correspond to equal actual distances:

10tttΔ=−tΔyΔ180120cos3.5d =0180yydΔ=1803213.53.5120cos2cos4cosd =×=×=dvt=Δ

represents the camera depression angle, the viewing distance c, and the distance y between the detection point and the camera are generally large. When the angle is small, it becomes very small compared to y. When ignoring changes in the shooting depression angle in the diagram and considering only the perspective generated by , we assume that all points in the detection zone maintain a constant elevation angle to the camera.

If the camera depression angle = 60° as shown in Figure 3 [Figure 3: see original paper]-7 for road traffic system surveillance cameras, then d = 10.5 m.

1.2 Video-Based Road Segment Traffic Volume Detection

By setting virtual detection zones in the video: a rectangular detection zone is placed on each lane region in the video image. Whenever a vehicle passes through the detection zone drawn in the lane, the visual information within that detection zone changes significantly, which serves as an important basis for determining whether a vehicle has passed through the detection zone. During detection, we analyze the data within the detection zone on each frame image to determine whether a moving target in the foreground has passed through the detection rectangle, and count the number of vehicles passing through each lane' s detection zone separately.

Common virtual detection methods include rectangular detection zones and detection line forms. This paper adopts the rectangular detection zone method as shown in Figure 3 [Figure 3: see original paper]. We ensure that the two parallel detection lines of the rectangular detection zone are perpendicular to the road. The size of the detection zone should be the same as the lane width. In practical applications, there may be slight differences due to the distance in road traffic surveillance video, and the distance between the two detection lines perpendicular to the lane must consider the influence of shooting distance.

The specific traffic volume detection algorithm detects moving targets, treats each target as a blob, and calculates the midpoint of each blob:

1122WxxHyy

where (x, y) are the midpoint coordinates of the moving target; (x , y) are the starting coordinates of the moving target region detected in the image; and W, H are the width and height of the moving target region, respectively.

Next, based on the calculated center point coordinates of the moving target, we draw a circular edge diagram with the detection zone width as the diameter. When the center point of the circular moving target in the edge diagram passes through the detection rectangle drawn for the corresponding lane, the traffic volume of that lane increases by 1. The traffic volume detection effect is shown in Figure 4 [Figure 4: see original paper].

2.1 Speed Dispersion

The mechanism of speed dispersion originates from different driving choices made by individual drivers. Even under identical road conditions, different drivers will select different speeds, which manifests at the macro level as road segment speed dispersion phenomena. Additionally, traffic flow characteristics and road features also influence drivers, contributing to speed dispersion.

Current research on speed dispersion has seen scholars propose various descriptive methods based on different research objectives. Widely recognized expressions include cross-section speed standard deviation (SD) [13] and average speed difference (ASD) [14]. Cross-section speed standard deviation is an effective indicator for representing sample dispersion, capable of showing the dispersion condition of individual vehicles relative to the average speed of all vehicles during the measurement period, and has been applied in many previous studies [15]. Higher standard deviation indicates more dispersed individual vehicle speeds, but it focuses more on describing cross-section speed dispersion. Additional processing is required to express the dispersion degree of the entire road segment. Average speed difference can reflect the speed difference relationship between adjacent vehicles from a spatial position perspective, but like cross-section speed standard deviation, it focuses more on cross-section speed dispersion without addressing the integrity of the road segment.

Existing research shows that vehicle speed and speed change rate are the main factors affecting driving safety [16], i.e., speed fluctuation amplitude. Therefore, we propose the concept of road segment-based vehicle speed dispersion _L, expressed as follows:

_L = (1/(M-1)) * Σ(V , - V)² (7)

V = (1/M) * ΣV , (8)

where V represents the 85th percentile speed, indicating that 85% of vehicles traveling on the road segment are below this speed while only 15% exceed it (speed cumulative frequency curve). This value effectively and objectively demonstrates the road segment speed. SL is the standard deviation of 85th percentile speeds across road segment cross-sections; V̄ is the average travel speed of vehicles passing through the entire road; V̄ is the average of 85th percentile speeds across all cross-sections; V , is the 85th percentile speed at the i-th cross-section; and M is the number of speed detection cross-sections on the road segment.

In formulas (7) and (8), the total number of cross-sections M is the only parameter requiring subjective determination. The more finely divided the cross-sections, the more accurate the calculation results, but overly dense cross-sections create significant difficulties in the detection process. Under the premise of convenient observation and calculation, increasing the number of cross-sections as much as possible ensures reasonable results. In this paper' s data processing, the cross-section spacing is maintained at approximately 50 m, which is both convenient for observation and prevents loss of result rationality due to too few cross-sections.

2.2 Road Segment Traffic Safety State Evaluation Method Based on Speed Dispersion

Based on the concept of road segment speed dispersion proposed in this paper, we can reflect the overall stable driving state of a road segment. From the perspective of individual vehicles, we can use the concept of single-vehicle speed fluctuation amplitude to reflect the stability of individual vehicle travel, and then infer the overall traffic state of the road segment.

We classify road segments into four levels based on road segment speed dispersion: Safe (A), Relatively Safe (B), Basically Safe (C), and Unsafe (D). Through statistical analysis of historical traffic data and accident severity levels from multiple road segments in Guangzhou, the evaluation index classification standards are shown in Table 1 . Here,¯_L represents the average speed dispersion during safe operation states of the road segment.

Table 1: Road Segment Traffic Safety Evaluation Index Classification Standards

Safety Level	Speed Dispersion _L (%)
Safe A	0–5.74
Relatively Safe B	5.74–11.48
Basically Safe C	11.48–17.22
Unsafe D	17.22–+∞

The threshold values corresponding to the four safety states of Safe A, Relatively Safe B, Basically Safe C, and Unsafe D are determined as [0, 5.74], (5.74, 11.48], (11.48, 17.22], and (17.22, +∞), respectively.

2.3 Evaluation Method Process

The specific evaluation steps for road traffic safety state based on road segment speed dispersion are as follows:

a) Input: Number of detection cross-sections M (positive integer) into which the road segment is divided, 85th percentile speed V , (i = 1, 2, ···, M) at the i-th cross-section, and average travel speed V̄ of vehicles passing through the entire road.

b) Calculate road segment speed dispersion: Compute the road segment' s speed dispersion _L using formula (7).

c) Calculate average speed dispersion under safe road conditions: The specific steps include: - (a) For each sample j (j = 1, 2, ···, K) of the road segment under safe operation state, where K is the total number of samples, calculate the speed dispersion _L, of sample j, starting with j = 1. - (b) Input the corresponding parameters for the j-th sample under safe operation state: number of detection cross-sections M (positive integer), 85th percentile speed V , (i = 1, 2, ···, M) at the i-th cross-section, and average travel speed V̄ of vehicles passing through the entire road. - (c) Calculate the speed dispersion _L, for sample j using the method determined in step b). - (d) Increment j = j + 1. If j K, return to step (b). - (e) Calculate the average speed dispersion ¯_L under safe road conditions using formula (9).

d) Match the calculated road segment speed dispersion _L with the road segment traffic safety state evaluation classification standard intervals to determine the safety level interval to which _L belongs.

The road safety state level corresponding to this interval is the evaluation result for that road segment' s safety state.

e) Output the road traffic safety state evaluation result.

The specific flowchart of the road segment traffic safety state evaluation method is shown in Figure 5 [Figure 5: see original paper].

3.1 Parameter Determination

This section uses traffic data from 10 samples of a road segment in Guangzhou for analysis. After analysis and screening, when the number of detection cross-sections M = 8, the experimental results are satisfactory. The speed dispersion values of samples under safe state conditions for this road segment are statistically analyzed as shown in Table 2 .

Table 2: Sample Speed Dispersion Under Safe Road State Conditions

Sample No.	Speed Dispersion _L (%)
1	4.21
2	5.92
3	5.68
4	6.01
5	5.89
6	5.43
7	5.12
8	5.76
9	5.21
10	5.98

From Table 2, we can derive the average speed dispersion under safe state conditions as¯_L = 5.74%. Consequently, the value ranges for road segment speed dispersion _L corresponding to the four safety states of Safe A, Relatively Safe B, Basically Safe C, and Unsafe D are [0, 5.74], (5.74, 11.48], (11.48, 17.22], and (17.22, $+\infty$), respectively.

3.2 Road Segment Safety State Evaluation

This section applies the proposed method to evaluate the safety state of a specific road segment. By analyzing real-time video information, we obtain the 85th percentile speeds V , (km/h) at the i-th cross-section passing through this road segment as: V , = 44.9, V , = 48.0, V , = 50.8, V , = 42.9, V , =

50.0, V , = 53.0, V , = 35.6, V , = 50.6. The average travel speed of vehicles passing through the entire road is V̄ = 50.6 km/h.

Using formula (9), we calculate the road segment speed dispersion as _L = 10.95%. By matching the calculated road segment speed dispersion with the road segment traffic safety state evaluation classification standard intervals, we determine that the speed dispersion _L belongs to the interval (5.74, 11.48], which corresponds to the Relatively Safe state level. Therefore, the evaluation result for this road segment' s safety state is Relatively Safe.

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4 Conclusion

This paper introduces the concept of road segment speed dispersion affecting urban road segment traffic safety from the perspective of speed variability, and combines video recognition technology to establish a road segment traffic safety state evaluation method based on road segment speed dispersion. The method can calculate real-time speed dispersion of a road segment based on video information, and then perform real-time evaluation of road traffic safety state according to the real-time speed dispersion. Experiments demonstrate that the proposed method is simple to implement, can provide reasonable evaluation of road safety states, and the evaluation results can provide a basis for traffic management departments to develop effective urban road segment traffic safety improvement programs. The method can utilize existing urban road surveillance equipment without requiring additional investment for implementation, thereby improving urban road segment traffic safety states with limited funds.

References

[1] Sun Lu, You Kesi. Review of urban road traffic safety evaluation research [J]. East China Highway, 2015 (1): 3-6.
[2] Gai Jingyuan. Research on road segment traffic safety evaluation method based on speed dispersion [D]. Nanjing: Southeast University, 2016.
[3] Dobromirov V, Evtiukov S, Duncheva E, et al. Methodology and results of traffic safety evaluation on the Saint Petersburg ring road [J]. Transportation Research Procedia, 2017, 20: 151-158.
[4] Fang Xueyang. Study on influence mechanism of speed dispersion on traffic safety under mixed traffic environment [D]. Nanjing: Southeast University, 2015.
[5] Wu Yihu, Wu Zhiping. Road segment safety analysis method based on average speed and speed standard deviation [J]. Journal of Highway and Transportation Research and Development, 2008, 25 (3): 139-142.
[6] Cao Binru, Liu Yong, Qian Wuyong, et al. Construction of the evaluation system for regional road traffic safety and application based on a grey integrated evaluation model [C]// Proc of IEEE International Conference on Grey Systems and Intelligent Services. 2015: 395-403.

[7] Li Yaoping, Li Jianlin, Li Bin, et al. Study on Road Traffic Safety Evaluation Based on Improved Bayes Model [J]. Applied Mechanics & Materials, 2011, 97-98: 489-493.
[8] Wang Yafei, Zhang Dongxue. Evaluation of road traffic safety in Huai Yin district of Jinan city based on AHP [J]. Applied Mechanics & Materials, 2014, 505-506: 1167-1171.
[9] Wei Wu, Zhang Qisen, Wang Mingjun, et al. Traffic parameter detection based on computer vision and image processing [J]. Information and Control, 2001, 30 (3): 257-261.
[10] Wang Chunbo, Zhang Weidong, Zhang Wenyuan. Visual detection of vehicles in complex traffic environments [J]. Journal of Shanghai Jiaotong University, 2000, 34 (12): 1680-1682.
[11] Stauffer C, Grimson W E L. Learning patterns of activity using real-time tracking [J]. IEEE Trans on Pattern Analysis & Machine Intelligence, 2000, 22 (8): 747-757.
[12] Shao Wenkun, Huang Aimin, Wei Qing. Survey of target tracking methods [J]. Image Technology, 2006 (1): 17-20.
[13] Park Y J, Mirandamoreno L F. Estimation of speed differentials on rural highways using multilevel models [C]// Proc of the 89th Annual Meeting of the Transportation Research Board. 2010: 1-6.
[14] Wang Hao, Wang Wei, Lu Jian, et al. Definition and characteristics of speed dispersion based on car-following theory [J]. Journal of Southeast University: Natural Science Edition, 2009, 39 (1): 161-165.
[15] Ren Yanming, Li Tiezhu, Sun Chan. Study on speed distribution characteristics of urban arterial road segments [J]. Journal of Transportation Engineering and Information, 2013, 11 (3): 98-105.
[16] Yang Yuan, Wei Wei. Research on highway vehicle speed evaluation based on safety degree [J]. Journal of Xihua University: Natural Science Edition, 2009, 28 (3): 39-42.

Note: Figure translations are in progress. See original paper for figures.