Retraction Notice

The Editor-in-Chief and the publisher have retracted this article, which was submitted as part of a guest-edited special section. An investigation uncovered evidence of systematic manipulation of the publication process, including compromised peer review. The Editor and publisher no longer have confidence in the results and conclusions of the article.

CH, SH, and YH did not agree with the retraction.

Intelligent rail transit signal control system based on image processing technology

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Abstract. With the rapid development of the intelligent rail field, the intelligent rail traffic signal control system plays an increasingly important role, bringing greater convenience to people's travel. Under normal circumstances, the trains are dispatched strictly according to the schedule, but in the daily operation of urban rail transit, the service is inevitably affected by many unpredictable uncertain factors. To ensure the safety of vehicles and smooth traffic, we proposed an intelligent rail traffic signal control system based on image processing technology. When the system detects that there are too many people waiting, it automatically adjusts the display time of the signal lights in real time according to the image, thus ensuring more time for passengers to get on the train, so as to realize the intelligent control of the track. The experimental results of our paper show that the accuracy of the improved vehicle target detection and recognition algorithm is more than 90%, which is higher than that of the algorithm without the improvement. Applying the proposed algorithm to image processing improved the recognition rate and accuracy. Through the test of the intelligent rail traffic signal control system based on image processing, it was found that the system effectively identified the number of people waiting in the lane and automatically adjusted the train closing time. The time required was only 1 s, and the responsiveness reached 99% to ensure the safety of vehicles and smooth traffic. *© 2022 SPIE and IS&T* [DOI: 10.1117/1.JEI.32.2.021607]

Keywords: smart track; vehicle object detection; image processing technology; traffic signal control system.

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1 Introduction

Intelligent urban rail transit includes subways, light rails, trams, maglev trains, and other types. Developing subway and light rail so that it occupies the dominant position in intelligent rail transit is an important way to solve urban traffic congestion in China. China has entered a period of great development of urban railway transportation, and some cities have transitioned from "line" construction to "network" construction. With the continuous construction and use of new lines in China and the gradual formation of urban railway transportation networks, future research hotspots will focus on train dispatching order and management. Improving the localization rate of signal systems has become another important issue related to the overall development of urban railway transportation. To ensure the safety and punctuality of trains, dispatching and command work is very important, and its importance is evident. The intelligent railway traffic signal control system is a comprehensive traffic management system that can function in a wide range and in any direction. The key to solving urban railway dispatch and command is keeping the service time strict and stable and improving the efficiency while ensuring traffic safety, which is the basis of urban railway dispatch and command.

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Over the past few decades, the rate of urbanization has grown rapidly, and the number people owning cars has grown exponentially. China enjoys rapid economic development, but the effect of urban concentration has become very significant, and the problem of urban congestion has grown exponentially in recent years. In an increasing number of cities, the urban transportation capacity and road traffic efficiency are obviously limited. The core of congestion lies in the limited growth of urban traffic capacity while the demand for road traffic grows substantially. Smart traffic is created if conservative solutions are cost-effective and feasible. The intelligent rail traffic signal control system is a comprehensive traffic management system that plays a wide range of roles. It has the remarkable characteristics of being real-time, highly efficient, and accurate, and it uses related advanced technologies such as control and signaling, which can effectively utilize existing road resources, reduce traffic exhaust emissions and air pollution, and improve road utilization efficiency. Intelligent transportation has become an important barrier for road safety, and governments around the world have paid attention to its related fields. The innovation of this paper is that it not only proposes a basic method based on image processing but also proposes an improved vehicle target detection and recognition algorithm, which greatly improves the detection rate and accuracy of the basic algorithm to more effectively ensure the intelligent rail transit's development.

2 Related Work

At present, significant development of urban rail transit has become an effective measure for some developed countries and regions in the world for solving urban traffic problems. Courtney Slavin found that improving the efficiency of urban transportation operations along major arterial roads is a top priority for many agencies, as congestion affects the flow of people and goods in many cities. Pedestrian exposure to traffic emissions is usually not a factor to consider when making traffic signal timing decisions.[1] Chandan found that, as the percentage of smart tracks in the total flow increased, the performance of the transportation system tended to improve. However, improving the control of traffic lights is still a challenging task due to the low penetration rate of current smart tracks.[2] Suresh found that the smart track is beneficial to human beings. The smart track not only solves the problem of road congestion but also saves a lot of time and cost for monitoring vehicles. But the traditional intelligent rail traffic signal control system has been unable to effectively control the track.[3] Ostojic designed a more effective signal control strategy that utilized and synthesized networked vehicle generation information to identify traffic conditions so that the controller could predict how the vehicle will drive. He proposed a framework for online signal control logic in a connected environment to respond to updated service requests for vehicle assignments.[4] Singleton found that existing pedestrian monitoring methods are often inefficient for collecting pedestrian data from many locations over a long period of time. He demonstrated the effectiveness of using a novel and relatively ubiquitous source of big data as a method for estimating the number of pedestrian stops. This information can be recorded and archived every time someone presses a pedestrian button or registers a pedestrian call at a signal light. His results show that traffic signal data can be successfully used to accurately estimate the pedestrian inbound traffic volume.[5] Scholars have found that urban rail transit is beneficial to the progress and development of society as it not only facilitates the movement of social masses but also saves people a lot of time. In the intelligent track, the traffic signal control system plays a very important role, so studying it is necessary.

Image processing is the technique of analyzing images with a computer to achieve a desired result. Image processing has been very significant and widely used in various fields, including engineering, medicine, and vehicle detection video processing. Ragan-Kelley found that image processing languages have proven to be effective systems for writing high-performance image processing code. Programmers simply provide the mapping of image processing to parallel machines, and the compiler performs the mechanical task of generating platform-specific code that implements scheduling.[6] Bennett proposed a method for processing high-precision measurements of information based on machine learning algorithms. A suggested configuration involves rapidly capturing pictures of incoming stops from smart track stops and then processing the images. The results showed that the determination of orbital stops is very accurate and the implementation is faster.[7] Shen incorporated the principle of image processing through a specially designed experimental setup. He meshed the image with a fine ink pen and recorded every moment with a digital camera. The grid map of the sample was obtained through image processing, and the accuracy was comparable to that of finite element analysis.[8] Aiming at the problems in intelligent rail transit, Santa proposed a new type of intelligent rail transit signal control system that consists of two subsystems: a hardware system and a software system. The software system was an image classification algorithm platform based on SVM classifier. The images produced during training and testing were obtained from the webcam in the system. Experimental results showed that the classification accuracy of the system was 100%.[9] By applying image processing technology to the intelligent rail traffic signal control system, scholars can improve the resolution and accuracy of the system, greatly improve the traffic efficiency of the intelligent rail and the safety rate of passengers, and decrease the time required to enter the station. However, academics have no experimental data to support these claims.

3 Vehicle Target Detection and Recognition Algorithm Based on Image Processing Technology

The urban rail traffic signal system is a key system for ensuring the safety of train operations, realizing the modernization of train operations, and improving the transportation efficiency. As an important branch of the urban intelligent rail traffic signal control system, the traffic signal control system not only ensures the orderly progress of road traffic but also ensures the safe passage of pedestrians and vehicles. When there are few or no vehicles passing through, the pedestrian waiting time is too long, which is a waste of road resources.[10] The intelligent rail traffic signal control system solves the increasingly serious traffic problems. With the continuous development of the economic and technological aspects, the intelligent rail traffic signal control system occupies an increasingly important position in traffic management, and its role is becoming increasingly obvious. The schematic diagram of the urban intelligent rail transit signal control system is shown in Fig. 1.

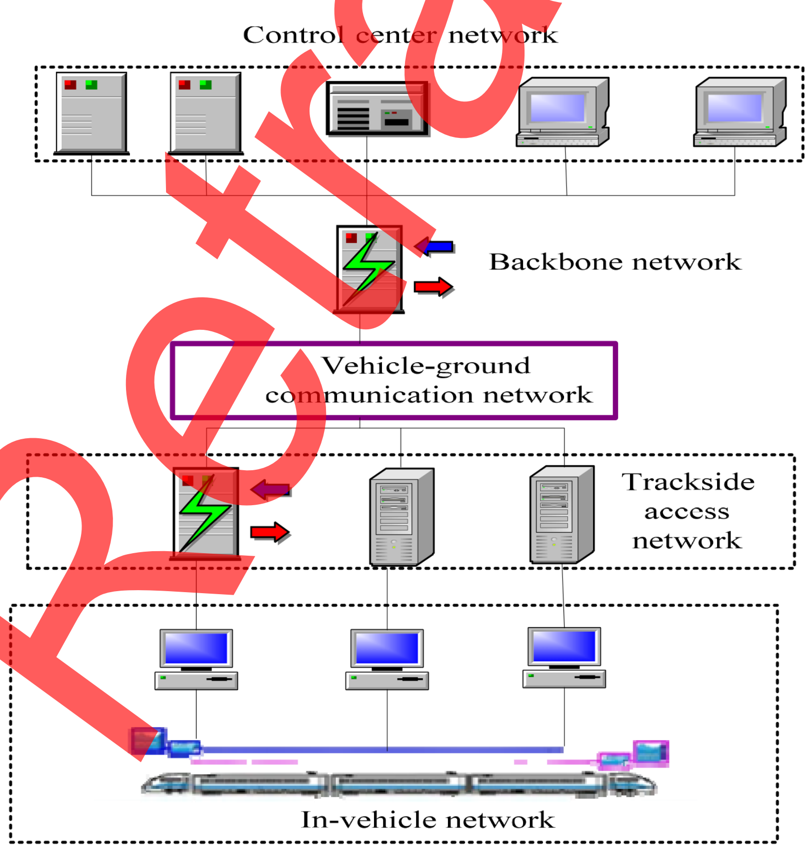


Fig. 1 Schematic diagram of urban intelligent rail transit signal control system.

As shown in Fig. 1, the urban rail transit signal control system is used for train interlocking, route control, train interval control, dispatch command, information management, equipment condition monitoring, and maintenance management, etc., thus forming an efficient and comprehensive automation system. However, various unreasonable situations originate from the traditional traffic light control method, and regardless of traffic conditions and pedestrian efficiency, traffic lights are only assigned a fixed duration.[11,12] Therefore, this paper proposes an intelligent traffic signal control system based on image processing technology to accurately detect the flow of people and vehicles. At the same time, the information of adjacent road conditions is shared to provide real-time data for the traffic signal control system to realize the real-time optimal adjustment and intelligent control of traffic lights. It not only saves the waiting time of pedestrians but also reasonably solves the problems of traffic congestion and difficult pedestrian crossing.[13]

3.1 *Basic Algorithm of Image Processing Technology*

3.1.1 *Image preprocessing*

Usually, the traffic flow video images captured by the video surveillance system are color images, and the video files are converted into video sequence images by video conversion technology, with the video images being complete images including color and brightness information. The amount of information stored is large, and the collected images are affected by various uncertain and changing factors such as weather, light, and wind, resulting in a lot of noise and a degradation of video image quality.[14] Homogeneous sampling directly records the exact value of the signal at a certain time point, so the sampling theorem only involves the ideal sampling process from continuous signal to discrete signal. To improve the quality of video images, reduce the amount of data storage, and obtain the most useful information in the images with maximum efficiency, a series of preprocessing operations are required for video images. Uniform sampling is represented by a matrix:

$$f = \begin{bmatrix} f_{11} & f_{12} & f_{1n} \\ f_{21} & f_{22} & f_{2n} \\ f_{m1} & f_{m2} & f_{mn} \end{bmatrix}. \tag{1}$$

A grayscale digital image is one with only one sampled color per pixel. Such images are typically displayed in grayscale ranging from the darkest black to the brightest white. The brightness values of the three components R, G, and B in the color image are used as the gray values of the three gray images, respectively, and one of the gray image methods is selected according to the actual situation, that is, the component method. The calculation formula is given as

$$B_1 = R, \;\; B_2 = G, \;\; B_3 = B \tag{2}$$

The grayscale image only retains the image brightness information and removes the color information. The three components of RGB in image grayscale are equal, that is, $R = G = B$. Therefore, the gray value is stored in only one byte, that is, 8 binary bits, and the gray level is 256, 0 is completely black, and 255 is completely white. The common method of image grayscale is the component method, and the calculation formula is given as

$$Y = \max\{R, G, B\}. \tag{3}$$

3.1.2 *Image filtering*

Image filtering is a key operation for improving image quality and reducing the effects of noise. Image noise refers to unnecessary or redundant interfering information that exists in image data. The existence of noise seriously affects the quality of remote sensing images. Image noise is an inevitable redundant interfering information in data images that seriously affects the image quality and image utilization. However, in the entire process from image acquisition to processing and use, there are many factors that generate image noise and are accompanied by randomness.[15] The noise signal has a strong visual effect, which has a serious impact on the detection and recognition of subsequent targets in digital image signals.

In simple terms, the neighborhood average method takes the average value of the surrounding circle for each pixel point to reduce the influence of some pixel value mutation points. Mean filtering uses the neighborhood averaging method to calculate the average value of all pixels in the template. After smoothing filtering, the processed image expression is obtained as

$$g(a,b) = \frac{1}{M}\sum_{i=1}^{M} f_i(a,b), \tag{4}$$

where M is the total number of pixels in the template and $f_i(a,b)$ is the pixel value in the template. A two-dimensional sliding window is used to traverse all pixels in the image; the expression is given in the following equation:

$$g(i,j) = \text{median}\{f(i,j)\}. \tag{5}$$

Usually, the size of the window can be 3×3, 5×5, and the shape of the window can also be a square, a circle, etc. In median filtering, differences in window size and shape often lead to huge differences in output. Median filtering can be processed according to the actual image processing object, and data can be selected from a variety of window sizes and shapes.[16] The median filter algorithm is shown in Fig. 2.

As shown in Fig. 2, median filtering is a nonlinear signal processing technique based on the ranking statistics theory that can effectively suppress noise. The traditional median filtering algorithm is simple: the value of the pixel in the center of the template is replaced by the mean value of each pixel in the neighborhood determined by the template, and the mean filtering template coefficients are all 1. The weighted average multiplies each value by the corresponding weight, adds and sums to get the overall value, and then divides by the total number of units. The Gaussian filter uses a weighted average method to calculate the mean, and its Gaussian function is shown in the following equation:

$$G(a,b) = \frac{1}{(\sqrt{2\pi\sigma})^2}, \tag{6}$$

where (a,b) is the coordinate of any pixel in the template, (a,b) is the coordinate of the center point of the template, and σ is the standard deviation. According to the properties of the normal distribution function, as the value of σ increases, the corresponding template size increases, the Gaussian function curve becomes smoother, the discretized template coefficient difference gradually decreases, and the image smoothing effect is better.[17]

Gaussian filtering is a linear smoothing filter that is suitable for eliminating Gaussian noise and is widely used in the noise reduction process of image processing. For a Gaussian filter

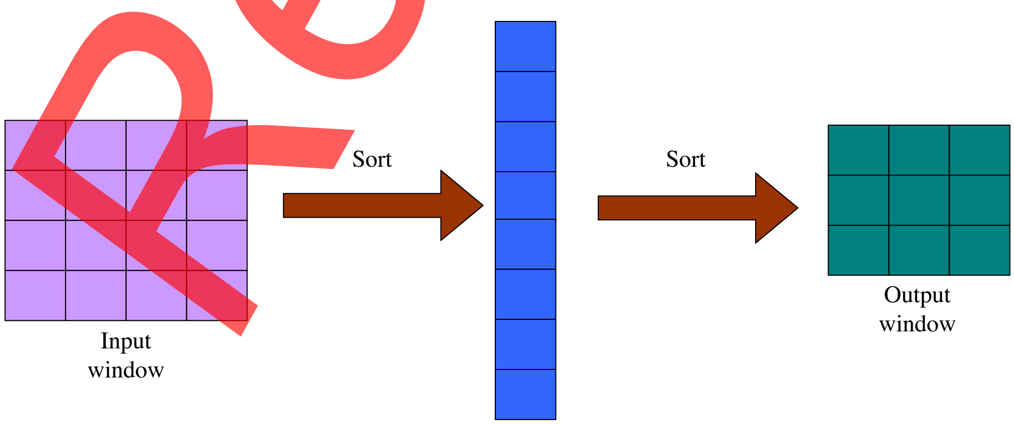


Fig. 2 Median filtering algorithm.

template, take the template center coordinate (0, 0) as the coordinate origin for sampling, and the coordinates of each position in the template are given in the following equation:

$$H(i,j) = \frac{1}{2\pi\sigma^2} e^{-\sigma^2}. \tag{7}$$

The method of reducing, suppressing, or eliminating noise to improve image quality is called image smoothing. After the analysis and comparison of different filtering algorithms, Gaussian filtering is used to smooth and denoise real-time traffic images.

3.1.3 *Grayscale transformation*

Grayscale transformation transforms the grayscale values of all points in an image according to a linear transformation function. If underexposed or overexposed, the grayscale image will be limited to a narrow range, and the monitor will display a grayscale image with no grayscale levels.[18,19] Grayscale expansion for each pixel can effectively improve the visual effect.[20]

If the gray level of the image is in the range (0 to 255), the gray level of most pixels is distributed in the interval $[a, b]$, and only a few gray levels exceed this interval. Then enhancement to improve the image quality must satisfy the following equation:

$$g(a,b) = \begin{cases} c, 0 \le f(a,b) \prec a \\ \frac{d-c}{b-a}[f(a,b) - a] + c, a \le f(a,b) \prec b \\ d, b \le f(a,b) \prec 255 \\ 0 \end{cases}. \tag{8}$$

The gray level of image $f(a,b)$ is in the range of (0, 255), and the gray level of the target image $g(a,b)$ is also in the range of (0, 255); then the function expression is given as

$$g(a,b) = \frac{c}{a} f(a,b). \tag{9}$$

The effect of the operation of this transfer function extends the grayscale of the original image from between a and b to between c and d. By selectively enlarging specific grayscale intervals, the distribution of the grayscale histogram can be controlled more flexibly, and the quality of the output image can be improved.

3.2 *Vehicle Target Detection and Recognition Algorithm and Improvement*

3.2.1 *Basic vehicle target detection and recognition algorithm*

In the process of vehicle operation, the phenomenon of mutual occlusion or overlap between vehicles will inevitably occur, that is, because there are two or more vehicles in the connected area at the same time, it is within the range to accurately determine the number of connected vehicles. Achieving segmentation of images is one of the key problems to be solved in vehicle counting. The vehicle target detection algorithm can achieve real-time detection while achieving high accuracy. The vehicle target detection and recognition algorithm is shown in Fig. 3.

As shown in Fig. 3, the background generally does not contain vehicles, but in the real-time detection system, there is almost no such situation, even if there is, it may not be obtained in time, so the background must be extracted from the pictures containing vehicles. The average value of a sequence of video images at the beginning of the system is taken as the background image, and the principle is given in the following equation:

$$B_k(i,j) = \frac{\sum_{k=0}^{N-1} I_k(i,j)}{N}, \tag{10}$$

where $B_k(i,j)$ represents the background image, $I_k(i,j)$ represents the image in the video sequence, and N is the frame number of the sequence image. The key to the mean method lies

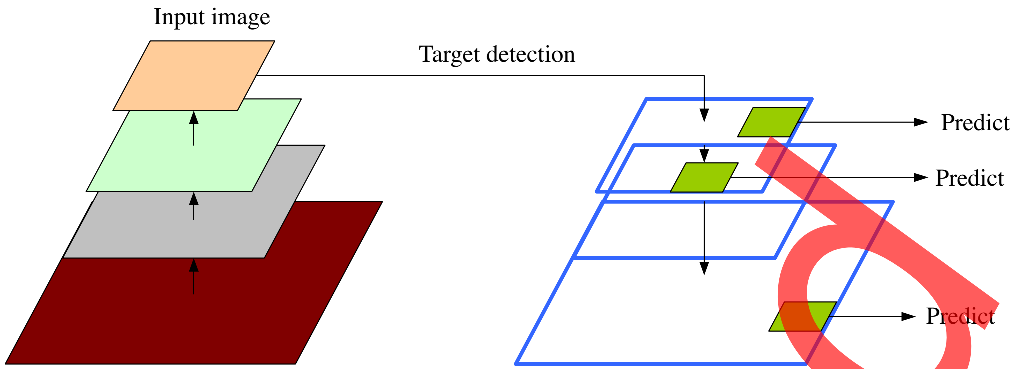


Fig. 3 Vehicle object detection and recognition algorithm.

in the selection of the number of frames N; if N is too small, the vehicle information cannot be effectively filtered out, causing interference. If N is too large, although the background image without the vehicle is obtained, it takes too long and affects the real-time performance of the system. According to a large number of experimental observations, it is found that, when N takes 150 to 200 frames, a better background image is obtained. The principle is given in the following equation:

$$B_k(i,j) = \mathrm{Med}(I_k(i,j)). \tag{11}$$

The key to this method is also the selection of N. Compared with the mean method, when N is 100 to 150 frames, a better background is obtained, that is, it takes 4 to 6 s, which shortens the time for the system to acquire the background and improves the real-time performance and stability of the system.

3.2.2 *Improved vehicle target detection and recognition algorithm*

In the target detection algorithm, the optical flow method has low detection efficiency and poor real-time performance in practical application scenarios. The background difference method can obtain a relatively complete scene, but the extracted scenes have significant differences in stability and reduced sensitivity that is accompanied by the appearance of noise. The interframe difference method can fully suppress and adapt to noise. Although it can ensure the change and stability of the external scene, it is accompanied by a serious double shadow phenomenon. The schematic diagram of the optical flow method is shown in Fig. 4.

As shown in Fig. 4, this paper adopts the method of combining the background difference method and the frame difference method to realize the extraction of moving targets, so the detected images can contain more target information. The background difference method is a method to detect moving objects by comparing the current frame in the image sequence with the background reference model, and its performance depends on the background modeling technique used. According to the mean background modeling method, for the k'th frame image $f_k(a,b)$ in the video sequence, sum and average the next N frames of consecutive images, and establish the k'th frame background image $B_k(a,b)$. Then according to Eq. (12), the image after background difference is obtained as

$$D_k(a,b) = |f_k(a,b) - B_k(a,b)|. \tag{12}$$

The binary image $G_{bk}(a,b)$ after background difference is obtained. For the test video sequence, the k'th video image is selected as the current frame image, and the image after background difference is given as

$$G_{bk}(a,b) = \begin{cases} 255, & D_k(a,b) > T \\ 0, & \text{else} \end{cases}. \tag{13}$$

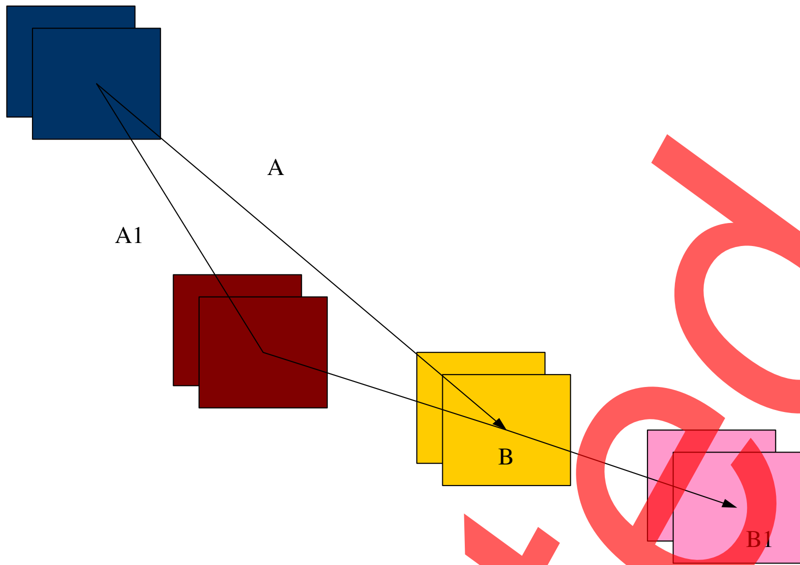


Fig. 4 Schematic diagram of the optical flow method.

The binary image after the three-frame difference of the k-frame image is given as

$$G_{fk}(a,b) = \begin{cases} 255, & G_{(k,k-1)} \cap G_{(k,k+1)} = 1 \\ 0, & G_{(k,k-1)} \cap G_{(k,k+1)} \neq 1 \end{cases}. \tag{14}$$

The three-frame difference algorithm is an improved method of the adjacent two-frame difference algorithm. It selects three consecutive frames of video images for the difference operation, eliminates the background influence due to motion, and extracts accurate contour information of moving objects. The moving target area in the binary image after three-frame difference processing includes the area covered by the target in the previous frame and the current frame. Therefore, the binary image $G_{bk}(a,b)$ obtained by the three-frame difference is calculated with the binary image obtained by the background difference, and the moving target area in the current frame is obtained as

$$G_{ek}(a,b) = G_{fk}(a,b) - G_k(a,b). \tag{15}$$

Next, the area covered by the moving target in the previous frame is derived. This part of the content should be included in the background frame with a larger update rate when the background is updated, as shown in the following equation:

$$G_k(a,b) = G_{fk}(a,b) \cap G_{bk}(a,b). \tag{16}$$

Combined with the proposed calculation method, the background update is slightly different in the improved moving target detection algorithm. The coverage area of the moving target passing through the previous frame should be updated to the background area with a larger update rate α in the current frame, and the background area pixels obtained by the background difference are updated with the update rate B. The calculation method is given as

$$B_k(a,b) = (1-\alpha)B_{k-1}(a,b) + \alpha f_k(a,b). \tag{17}$$

A binary image is one in which each pixel on the image has only two possible values or gray level states. People often use black and white and monochrome images to represent binary images. Aiming at the foreground image of the vehicle in the binary image and observing the outer contour of the vehicle, it can be found that the convex hull area of the vehicle is significantly larger than that of the nonadhesive vehicle when the vehicle is stuck. Therefore, whether there is a stuck vehicle can be determined by calculating the ratio of the area of the foreground area of the vehicle to the area of the peripheral convex hull. The calculation formula is given in the following equation:

$$R_A = \frac{R_v}{R_c}, \tag{18}$$

where R_v is the area occupied by the foreground area of the vehicle and R_c is the area enclosed by the convex closed envelope of the vehicle.

4 Experiment of Traffic Signal Control System Based on Image Processing Technology

4.1 *Development of Intelligent Rail Transit*

The proposed algorithm is simulated and tested on a Win7 computer with Intel Core i5-4210M CPU, with a main frequency of 2.6 GHz and a 4 GB memory configuration. It uses MATLABR2016a as the algorithm development test environment. According to the method described in this paper, the durations of vehicle and pedestrian tracks are designed, respectively, and the actual survey is carried out for the driving conditions of urban road vehicles.

With the development of intelligent transportation, intelligent signals have become an effective control device for urban vehicles and pedestrians. Most of China's signal light control systems use advanced intelligent traffic signal control systems from other countries or improved systems based on the characteristics of road traffic. The system adopts a fixed timing control method according to the road traffic flow information in different periods. The development of the smart track from 2015 to 2018 is shown in Fig. 5.

As shown in Fig. 5, in recent years, the development of smart track shows that it effectively alleviates road traffic congestion to a certain extent. However, there are still problems such as the uneven distribution of traffic time between vehicles and pedestrians, long waiting times, and the waste of resources due to fixed timing. This paper focuses on the research work of the intelligent traffic signal control system based on image processing. Image processing technology is used to process the real-time passing video of vehicles and pedestrians, and control technology is used to dynamically allocate the passing time according to the real-time data of vehicles and pedestrians. In this way, real-time data can be grasped in time, intelligent control can be realized, the passing speed of vehicles and pedestrians can be improved, the number of vehicle stops and the waiting

Fig. 5 Development of smart track from 2015 to 2018.

time of pedestrians can be reduced, resources can be saved, and the environment can be protected.

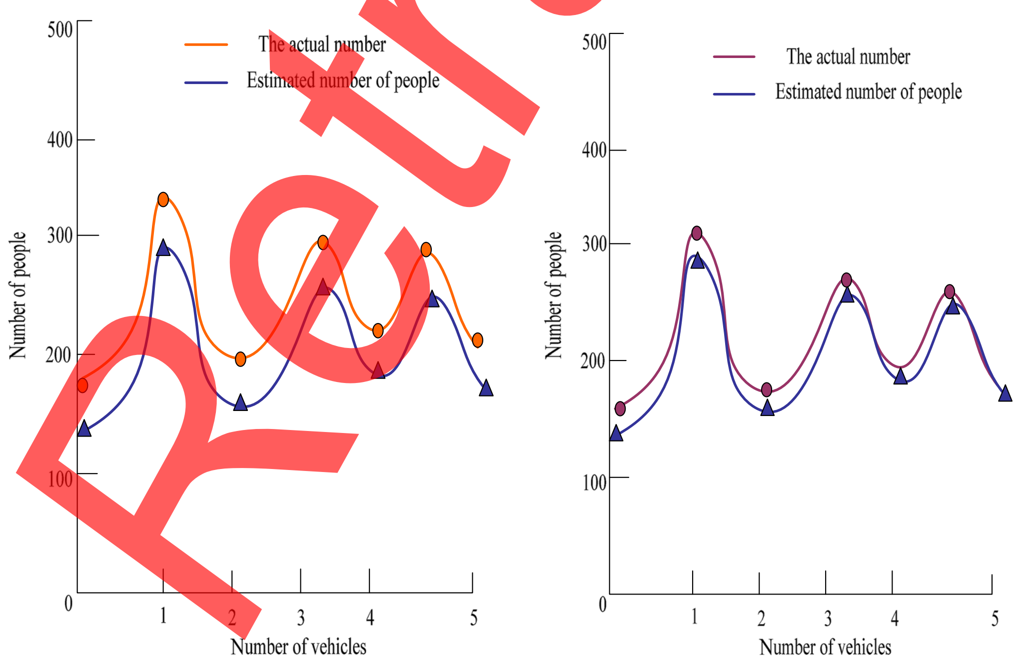
4.2 *Vehicle Target Detection and Recognition Algorithm Experiment Before and After Improvement*

In an actual motion scene, the shadow of the vehicle is generated due to the occlusion of the light by the moving vehicle. In the foreground detection of the vehicle target, the shadow of the vehicle is detected as the foreground area, causing the shape and size of the vehicle itself to change and affecting the foreground extraction of the target vehicle. The error of the vehicle target detection and recognition algorithm before and after the improvement is shown in Fig. 6.

As shown in Fig. 6, the error difference of the vehicle target detection and recognition algorithm before and after the improvement is still relatively large, the error of the algorithm before the improvement is more obvious, and the error of the improved algorithm is small. It can be seen that the improved algorithm is more suitable for image processing technology. In the vehicle counting simulation experiment, vehicle driving videos from the Internet and vehicle videos captured by mobile phones are used as test videos. The detection rate of the vehicle target detection and recognition algorithm before and after the improvement are compared by experiments to verify the accuracy of the proposed improved vehicle detection and counting method.

The results of the test video of the vehicle target detection and recognition algorithm before and after the improvement are shown in Tables 1 and 2, respectively.

As shown in Tables 1 and 2, there are 38 vehicles in the first experiment; the number of vehicles detected by the vehicle target detection and recognition algorithm before improvement is 32, and the detection rate is 84.2%. The number of vehicles detected by the improved vehicle target detection and recognition algorithm is 37, and the detection rate is 97.3%. With the increase of vehicles, the detection rate of both algorithms decreases, but the detection rate of the improved vehicle object detection and recognition algorithm is maintained at a high level. It seems that the detection rate of the improved vehicle target detection and recognition algorithm is higher than that of the vehicle target detection and recognition algorithm before the improvement.



(a) The error of the algorithm before the improvement (b) The error of the improved algorithm

Fig. 6 Error of vehicle object detection and recognition algorithm before and after improvement: (a) the error of the algorithm before the improvement and (b) the error of the improved algorithm.

Table 1 Detection rate of vehicle object detection and recognition algorithm before improvement.

Number of experiments	Total vehicle	Number of detected vehicles	Error	Accuracy (%)
1	38	32	6	84.2
2	40	35	5	87.5
3	42	36	6	85.7
4	44	37	7	84.1
5	46	39	7	84.7

Table 2 Detection rate of the improved vehicle object detection and recognition algorithm.

Number of experiments	Total vehicle	Number of detected vehicles	Error	Accuracy (%)
1	38	37	1	97.3
2	40	38	2	95.0
3	42	40	2	95.2
4	44	41	3	93.1
5	46	42	4	91.3

This also shows that the proposed improved vehicle object detection and recognition algorithm basically realizes the accurate counting of different vehicle video streams; it not only accurately locates the position of a single vehicle to realize vehicle detection but also reduces the vehicle counting error. It can be seen from the experimental results that the proposed improved algorithm can meet the needs of the actual system and has a better detection ability.

4.3 *Performance Comparison of Algorithms in Different Environments*

The system works over a long time period, during which the background changes greatly and must be updated in real time, so experiments in different environments are more contrastive. The following are the results of 100 vehicles in different environments, as shown in Tables 3 and 4.

Table 3 The results of the vehicle target detection and recognition algorithm before improvement in sunny weather.

Total number of vehicles	Detected vehicle	The detected vehicle is not	Accuracy (%)
100	97	3	97
100	96	4	96
100	95	5	95
100	95	5	95
100	97	3	97

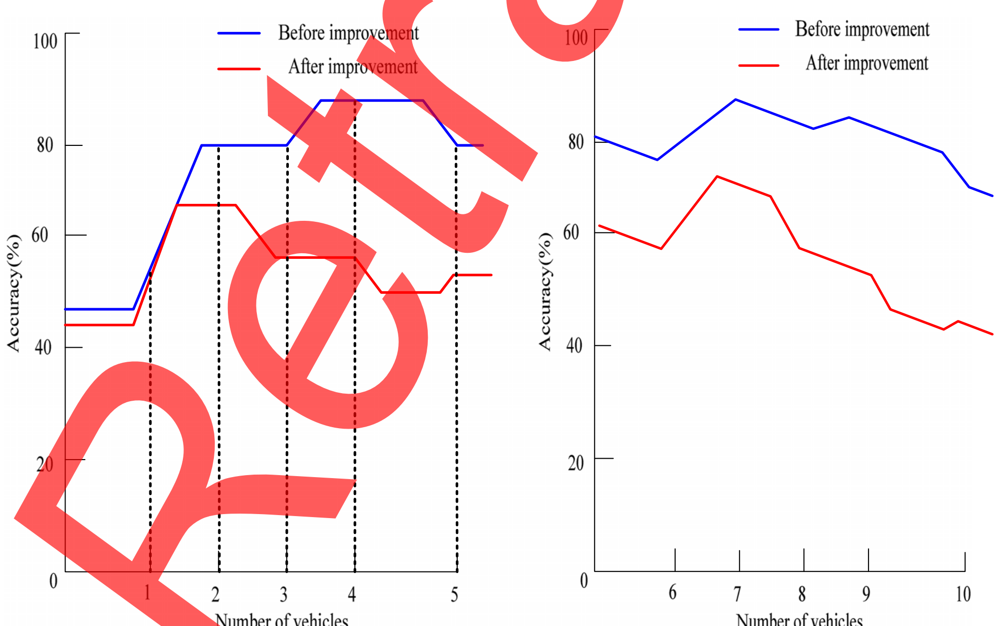
Table 4 Results of the improved vehicle target detection and recognition algorithm in sunny weather.

Total number of vehicles	Detected vehicle	The detected vehicle is not	Accuracy (%)
100	98	2	98
100	97	3	97
100	95	5	95
100	96	4	96
100	95	5	95

As shown in Tables 3 and 4: the detection accuracy of the algorithms before and after the improvement is above 95% in sunny weather, and there is no big difference. The vehicle count of the improved vehicle target detection and recognition algorithm is a little more accurate than that of the algorithm before the improvement. Because it only counts 100 vehicles, the weather conditions are better, the time is shorter, and the background changes are not very obvious.

To verify the stability of the proposed improved algorithm, this paper conducts experiments on the two algorithms in cloudy and rainy weather environments, as shown in Fig. 7.

As shown in Fig. 7, it can be seen from the comparison of the experimental results that the proposed improved moving target detection algorithm has a high detection efficiency, and the robustness of moving target detection and extraction in complex environments is strong. The system implements an intelligent traffic timing scheme based on the digital image processing algorithm. Different from the previous traffic system, this system automatically adjusts and displays the time that the railway vehicle stays after detecting that there are too many people waiting in the lane. The image processing time is only about 1 s, which is efficient and real time and can effectively reduce congestion and ensure vehicle safety.



(a) The accuracy of the algorithm before the improvement in the rainy weather environment

(b) The accuracy of the improved algorithm in the rainy weather environment

Fig. 7 Comparison of the two algorithms in rainy weather: (a) the accuracy of the algorithm before the improvement in the rainy weather environment and (b) the accuracy of the improved algorithm in the rainy weather environment.

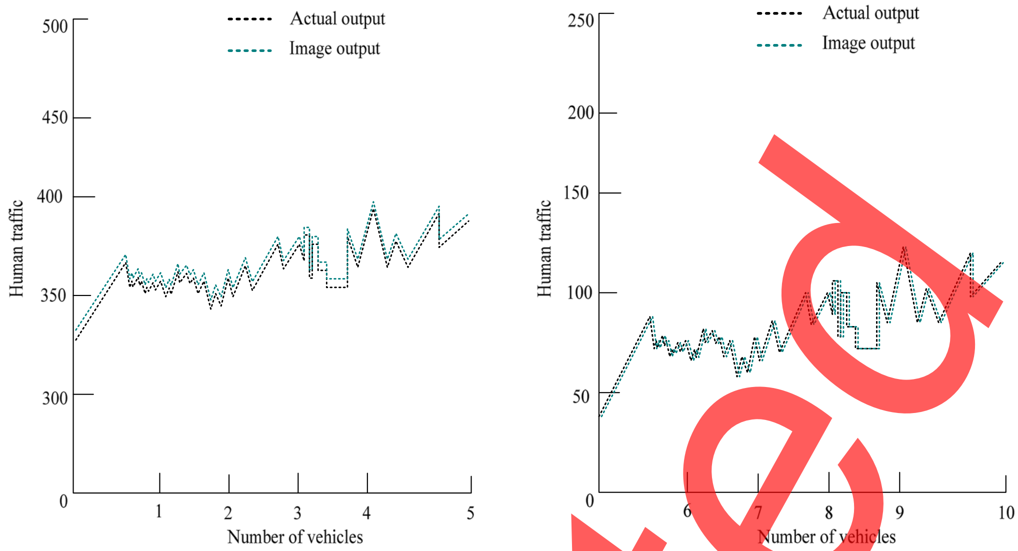


Fig. 8 Test of intelligent rail transit signal control system based on image processing.

4.4 *Performance Test of Intelligent Rail Traffic Signal Control System*

According to the actual survey of pedestrians entering the station on the urban intelligent rail and the time relationship between pedestrians entering the station and vehicles, the maximum number of pedestrians waiting for each carriage is set to 20. Pedestrians' pit-stop speed varies with the pedestrian's age, physical condition, waiting time, and other factors. Young people's pit stops are faster than those of middle-aged and elderly people, men's pit stops are faster than women's, and pedestrians' pit-stop speeds increase when the track stop time is shorter. The test of the intelligent rail transit signal control system based on image processing is shown in Fig. 8.

As shown in Fig. 8, the output results of image processing are basically the same as the actual surveyed track traffic conditions. The difference is that, through the moving time of image processing, the decision of the next cycle of the signal light duration is realized, and a real-time intelligent adjustment is achieved. It solves the current situation of unreasonable track stay allocation time brought by the traditional relatively single-fixed timing scheme and accurately outputs the track stay time required according to different traffic flows.

The output result of pedestrian image processing is suitable for the actual time required for pedestrians to enter the station. When the number of pedestrians is small, the output time of the track corresponding to the pedestrian's entering speed is selected. In the case of a large number of pedestrians, the corresponding track stop output time when the pedestrian entering speed is small is selected as the actual time required for pedestrians entering the station. After testing, the image processing technology can meet the needs of the actual pedestrian inbound signal control time.

5 Conclusions

The traffic signal control system is a real-time networked control system for regional traffic signals that integrates modern computer, communication, and control technologies. "Safety and punctuality" are the advantages of urban rail transit, and these are the working goals of the traffic signal control system. The reliability of various rail transit systems and equipment, the safety of the operation process, and the timeliness of handling accidents and failures are the three most important factors for safety and punctuality. Ensuring the safety of passengers is the most important core issue, and the number of people taking rail trains is increasing, which leads to danger arising from crowding. The subway generally opens and closes doors automatically. If the vehicle causes safety problems, the consequences will be disastrous. Therefore, this paper proposes applying the image processing technology to the intelligent rail traffic signal control system. The image processing technology can effectively identify the vehicle status and the flow of people in time and control the train signal, so the safety problem can be solved. In the experiment, this paper conducts a comparative experiment on the vehicle target detection and recognition algorithm before and after the improvement in image processing and finds that the improved target detection algorithm has a higher accuracy; thus it is also effective for applying to the detection of pedestrians. Due to the author's negligence, there are still many problems in this paper. The author's professional knowledge is limited, but he will continue to learn and strive for progress. Many problems still exist within the study of traffic signal control systems, and these will be the subject of future research.

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Data Availability Statement

The datasets generated and/or analyzed for the current study are not publicly available due to their sensitivity and the data use agreement.

References

1. C. Slavin and M. A. Figliozzi, "Impact of traffic signal timing on sidewalk-level particulate matter concentrations," *Transport. Res. Rec.* **2340**(1), 29–37 (2013).
2. K. Chandan, A. Seco, and A. Silva, "A real-time traffic signal control strategy under partially connected vehicle environment," *Promet Traffic Transport.* **32**(1), 61–73 (2019).
3. G. B. Suresh and V. Mathivanan, "Detect and track contamination of smart structure in marine atmospheres," *Pollut. Res.* **37**(2), 466–468 (2018).
4. M. Ostojic and H. S. Mahmassani, "Evaluation of traffic signal systems effectiveness in connected vehicle environments using trajectory analytics," *Transport. Res. Rec.* **2675**(11), 509–521 (2021).
5. P. A. Singleton and F. Runa, "Pedestrian traffic signal data accurately estimates pedestrian crossing volumes," *Transport. Res. Rec.* **2675**(6), 429–440 (2021).
6. J. Ragan-Kelley et al., "Halide: decoupling algorithms from schedules for high-performance image processing," *Commun. ACM* **61**(1), 106–115 (2017).
7. A. Bennett, E. Davidovitch, and Y. Beiderman, "Corneal thickness measurement by secondary speckle tracking and image processing using machine-learning algorithms," *J. Biomed. Opt.* **24**(12), 1–10 (2019).
8. L. Shen, C. Qiu, and W. U. Xiaoyan, "Thick plate bending and image processing algorithms assistant for deformation process discretization analyses," *Mechanika* **26**(5), 383–389 (2020).
9. F. M. Santa, H. Montiel, and F. Martínez, "Blueprints obtention by means of using digital image processing algorithms," *Int. J. Eng. Technol.* **10**(4), 1129–1135 (2018).
10. R. Saussard, B. Bouzid, and M. Vasiliu, "A novel global methodology to analyze the embeddability of real-time image processing algorithms," *J. Real-Time Image Process.* **14**(3), 565–583 (2018).
11. E. Fauster, D. C. Berg, and D. Abliz, "Image processing and data evaluation algorithms for reproducible optical in-plane permeability characterization by radial flow experiments," *J. Compos. Mater.* **53**(1), 45–63 (2019).
12. Z. Xu, M. M. Kamruzzaman, and J. Shi, "Method of generating face image based on text description of generating adversarial network," *J. Electron. Imaging* **32**(5), 051411 (2022).

13. G. Gu, L. Liu, and W. Jia, "Research of processing algorithms for rail crack infrared image," *Tiedao Xuebao/J. China Railway Soc.* **40**(11), 129–133 (2018).
14. C. Musik and M. Zeppelzauer, "Computer vision and the digital humanities: adapting image processing algorithms and ground truth through active learning," *VIEW J. Eur. Telev. Hist. Cult.* **7**(14), 59–72 (2018).
15. S. Hu, "Research on data acquisition algorithms based on image processing and artificial intelligence," *Int. J. Pattern Recognit. Artif. Intell.* **34**(06), 1–13 (2020).
16. A. Nasirullah, "A general structure for scheming image processing algorithms for intelligible polarimetric images," *Int. J. Mod. Trends Sci. Technol.* **6**(8S), 28–30 (2020).
17. A. Al-Marakeby, "Cache memory loaclity optimization for implementation of computer vision and image processing algorithms," *J. Al-Azhar Univ. Eng. Sector* **15**(55), 604–613 (2020).
18. U. Amrutha, "Detection of vehicle damages using image processing algorithms—a tensor flow-based approach," *J. Adv. Res. Dyn. Control Syst.* **12**(SP4), 817–822 (2020).
19. M. Bandi and V. George, "An isolated traffic signal design using a GA-based optimization technique," *Int. J. Recent Technol. Eng.* **8**(5), 2598–2604 (2021).
20. D. S. Hurwitz et al., "Traffic signal system misconceptions across three cohorts: novice students, expert students, and practicing engineers," *Transport. Res. Rec.* **2414**(1), 52–62 (2014).

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