Research on Video-based Moving Vehicle Detection Technology

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Abstract. Moving vehicle detection technology has been used more and more widely in monitoring traffic conditions such as vehicle flow, vehicle speed, traffic accidents, and escape from violations. The most commonly used methods of moving vehicle detection technology include the inter-frame difference method, the background difference method, and the optical flow method. The inter-frame difference method subtracts the images of two or three adjacent frames, the pixel whose brightness change does not exceed the threshold value is considered as the background, and the pixel whose brightness change exceeds the threshold value is considered as the foreground; The background difference method uses a difference comparison between the current image and the background model to realize the moving vehicle detection; The optical flow method is to construct an optical flow field by changing the brightness value of each pixel point in an adjacent frame in a video image, and realize the detection of a moving vehicle through a moving field of the moving vehicle. The frame difference method can detect the contour edge information of a moving vehicle, and the detection result is less noisy; the background difference method can detect a more complete moving vehicle, including not only the contour information of the moving vehicle, but also the connected area inside the moving vehicle; The optical flow method can detect moving vehicles, but can only obtain the contour edge information of moving vehicles, and there are large voids in the interior of moving vehicles. In short, these methods can realize the detection of moving vehicles, but there are still some problems. With the research and implementation of improved algorithms, the detection technology of moving vehicles will be more and more widely used.

Keywords: moving vehicle detection, inter-frame difference method, background difference method, optical flow method
1. Introduction

Video-based moving vehicle detection technology is often used in the military field and government departments, financial institutions, airports and railway stations with high security requirements. But as the ordinary people's living standards unceasing enhancement, people's daily activities areas, such as highways, shopping plazas, school areas and exhibition halls, are installed with surveillance video, which can perform real-time detection and tracking of pedestrians and vehicles. Real-time protection of pedestrians' personal safety, real-time monitoring of traffic conditions such as traffic volume, speed, traffic accidents and escape from regulations [1-2]. These situations have led to the detection of moving vehicles as a hot research area for digital image processing, which has produced more and more economic benefits and application values in human life.

In recent years, scholars at home and abroad have put forward many methods for moving vehicle detection. In order to improve the accuracy, real-time, and robustness of moving vehicle detection technology under different conditions, scholars at home and abroad have put forward many improved methods. There are three most common methods of moving vehicle detection technology based on video images: inter-frame difference method [3-4], background difference method [5], and optical flow method [6-7].

2. Inter-frame difference method

2.1. Principle and Algorithm of Inter-frame Difference Method

The method of inter-frame difference is to operate on the frames in the video image sequence. This operation is pixel-based and subtracts two or three adjacent frames to obtain the contour of the moving vehicle, which is very suitable for the situation where multiple moving targets and move successively. When the abnormal movement of moving vehicles occurs in the monitoring scene, there must be a significant difference between the two frames of the image. First, a difference operation is performed on the images of two adjacent frames to obtain a difference image, and then the difference image is binarized. In the case of a certain environment change, if the corresponding pixel value changes less than a predetermined threshold, the pixel point is considered as the background. If the pixel value in the image area changes greatly, it can be considered as a moving vehicle. These areas are marked as foreground and the marked pixel area can be used to determine the position of the moving target in the image, by this method can analyze the moving vehicles in image or video sequence.

The inter-frame difference method is to subtract the corresponding pixel values of the image of adjacent frames to obtain a difference image. Set the n-th and n-1-th frames in the video sequence to $f_n$ and $f_{n-1}$, and the gray values of the corresponding pixels of the two frames are recorded as $f_n(x,y)$ and $f_{n-1}(x,y)$, according to the formula (1) the two corresponding pixel point gray value of image subtraction, and take its absolute value, get the differential image $D_n$:

$$D_n(x,y) = |f_n(x,y) - f_{n-1}(x,y)| \quad (1)$$

The threshold value $T$ is set, and the pixel points are binarized according to formula (2) to obtain the binary image $R_n'$. The point with a gray value of 1 indicates that the gray level of the pixel has changed greatly at different times, that is, a moving vehicle point, and the point with a gray value of 0 indicates that the gray level of the pixel has not changed or changed very small, which is the point of non-moving vehicles. The connectivity analysis of the image $R_n'$ can finally obtain the image $R_n$ containing the complete moving vehicle.
2.2. Implementation of the inter-frame difference method

The inter-frame difference method is used to detect moving vehicles. First, the program reads video frames and converts the read video frames into gray images. Then the pixel points corresponding to the two adjacent frames are differed, and the difference image is binarized, and compares the obtained gray value with a set threshold to determine whether the pixel point is a moving vehicle point or a background point. In this process, the background is continuously updated. Finally, mathematical morphology is used to detect the area of the changed image block in the foreground image. The proportion of the image block accounts for more than 40% of the entire changed area. It can be considered as a moving vehicle, circulation processing, until the end of video processing.

\[
R'_t(x,y) = \begin{cases} 
1, & D_n(x,y) > T \\
0, & \text{else}
\end{cases}
\]  

(2)

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Figure 1 is the 36th frame of the video, Figure 2 is the 37th frame of the video, and the difference between the two frames is used to obtain the detection result of Figure 3. Figure 4 is the 91st frame of the video, and Figure 5 is the 92nd frame of the video. The difference between the two frames is used to obtain the detection result of Figure 6. Through the detection results, it can be found that the result detected by the inter-frame difference method is less noisy, but only the contour edge information of the moving vehicle can be obtained. There are isolated points and a small number of disconnected areas inside the contour, and there are large voids inside the moving vehicle. Although the inter-frame difference method has the advantages of small memory consumption, small calculation amount, and simple algorithm, but the algorithm depends on the choice of the threshold and the threshold is too small easy to introduce too much noise, a threshold is too large to lead to test result is not complete, so you need to study the optimal threshold selection algorithm to improve the detection effect of inter-frame difference method and results.

3. Background difference method

3.1. Principles and Algorithms of the Background Difference Method

The background difference method is a method to detect moving vehicles by differential operation between the current frame image and the background image. The method stored in advance or real-time update the background image sequence to model each pixel of the image to obtain the background model \( f_b(x, y) \), and the current of every frame image \( f_t(x, y) \) and background model \( f_b(x, y) \) subtraction operation to obtain the pixel points in the image that a large deviate from the
background image and set the threshold value $T_0$. If the absolute value of the subtraction value is greater than the threshold value $T_0$, the pixel point is a moving vehicle point, and the pixel value is 1. If the absolute value of the subtraction value is less than the threshold value $T_0$, the pixel value is The point is a background image point, and the pixel value is 0. The calculation formula is as follows:

$$f(x, y) = \begin{cases} 1, & |f_i(x, y) - f_b(x, y)| > T_0 \\ 0, & \text{else} \end{cases}$$

(3)

By traversing each pixel point through the above steps, a moving vehicle can be completely segmented. The background difference method is simple and easy to implement, which has been widely used by many scholars and researchers. But it is important to note that when the background image changes slightly for a long time or a large change occurs within a short period of time, the pre-stored background image needs to be updated, otherwise, as the growth of the time, the cumulative error is more and more big, will cause the background image and the actual background image of the larger deviation, directly lead to the failure detection.

3.2. Implementation of the background difference method

The background difference method is used to detect moving vehicles. First using the program read the video frame and will convert the read video frames into grayscale images. Then the image is modeled to obtain the background model. The background is detected by extracting continuous multi-frame images. After detecting background pixels and pre-sports attractions, in this process, the model needs to be updated, and the background needs to be continuously updated. The area of the image block area in the foreground image is detected, and the proportion of image blocks exceeds the set threshold. It can be regarded as a moving vehicle, circulation processing, until the video processing ends.

Figure 7. The 37th frame  
Figure 8. The detection result

Figure 9. The 92nd frame  
Figure 10. The detection result

Figure 7 is the 37th frame of the video. The detection result of Figure 8 is obtained by the background difference method. Figure 9 is the 92nd frame of the video. The detection result of Figure 10 is obtained by the background difference method. Through the detection results, it can be found from the detection results that the background difference method can detect a more complete moving vehicle, including not only the contour information of the moving vehicle, but also the connected areas inside the moving vehicle. However, the algorithm is more sensitive to light changes and it is easy to detect more noise. At the same time, the algorithm has a large amount of calculation, high complexity, and parameters are difficult to adjust. So it is necessary to study and improve the algorithm to solve the above problems.
4. Optical flow method

4.1. Principle and Algorithm of Optical Flow Method

The optical flow field is a concept first proposed by Gibson in 1950. Optical flow is the instantaneous speed of each pixel movement on the corresponding two-dimensional image of a moving vehicle in space. It is caused by the movement of a moving vehicle, the movement of a photographing machine, or both. When there is a moving vehicle in the image, because the moving vehicle and the background of the image have relative motion, the speed vector formed by the moving vehicle must be different from the speed vector of the background, so that the position of the moving vehicle can be detected. If there is no moving vehicle in the image, then the optical flow vector changes continuously throughout the image area.

It is assumed that the gray value of pixel \((x, y)\) at time \(t\) is \(I(x, y, t)\). At time \(t + dt\), the pixel moves to a new position \((x + dx, y + dy)\) and the gray value is \(I(x + dx, y + dy, t + dt)\). According to the consistency assumption of the image, when \(dt \rightarrow 0\), the brightness of the image along the motion trajectory remains unchanged [8], that is:

\[
I(x, y, t) = I(x + dx, y + dy, t + dt)
\]  \hspace{1cm} (4)

If the image gray value \(I(x, y, t)\) changes, the above formula is expanded by Taylor series:

\[
I(x + dx, y + dy, t + dt) \approx I(x, y, t) + \frac{\partial I}{\partial x} dx + \frac{\partial I}{\partial y} dy + \frac{\partial I}{\partial t} dt
\]  \hspace{1cm} (5)

In the formula, \(I_x = \frac{\partial I}{\partial x}, I_y = \frac{\partial I}{\partial y}, I_t = \frac{\partial I}{\partial t}\) represent the change rate of the gray level of the reference point with \(x, y,\) and \(t\); \(u = \frac{dx}{dt}, v = \frac{dy}{dt}\) represent the moving speed of the reference point along the \(x\) and \(y\) directions, that is, optical flow. Formula (6) is the basic equation of optical flow, written as a vector form:

\[
\nabla I \cdot U + I_t = 0
\]  \hspace{1cm} (6)

In the formula, \(\nabla I = [I_x, I_y]\) represents the gradient direction, and \(U = [u, v]^T\) represents the optical flow. Formula (7) is called the optical flow constraint equation and is the basis of all gradient-based optical flow calculation methods.

Considering the two-dimensional space composed of \(u\) and \(v\), then Formula (7) defines a straight line, all \(U = [u, v]^T\) satisfying the constraint equation are on the straight line, and the straight line is perpendicular to the gradient \(\nabla I = [I_x, I_y]\). Since the optical flow constraint equation contains two unknown quantities, it is clear that one equation cannot be uniquely determined. In order to solve the optical flow field, new constraints must be introduced. According to different constraint conditions, the gradient optical flow method is divided into global constraints and local constraints. The global constraint method assumes that the optical flow satisfies certain constraints of the entire image range, and the local constraint method assumes that the optical flow satisfies certain constraints in a small area around a given pixel point.

The Horn-Schunck algorithm is one of the global constraint methods, it proposes the smoothness constraint of optical flow, that is, the optical flow of any pixel in the image is not independent, and the
optical flow changes smoothly throughout the entire image range. The so-called smoothing means that the integral of the square sum of the velocity components is the smallest in a given field:

$$S = \int \int (u_x^2 + u_y^2 + v_x^2 + v_y^2)\,dx\,dy$$  \hspace{1cm} (7)

In practice, Formula (8) can be replaced by the following expression:

$$E = \int \int (u - \bar{u})^2 + (v - \bar{v})^2\,dx\,dy$$  \hspace{1cm} (8)

Where $\bar{u}$ and $\bar{v}$ represent the mean values in the field of $u$ and the field of $v$, respectively.

According to the optical flow basic Formula (7), considering the optical flow error, the Horn-Schunck algorithm reduces the optical flow solution to the following extreme value problem:

$$F = \int \int [ (I_x u + I_y v + I_z) + \lambda (u - \bar{u}) + (v - \bar{v}) ]\,dx\,dy$$  \hspace{1cm} (9)

Where, $\lambda$ controls the smoothness, the value of it must consider the noise situation in the figure. If the noise is stronger, it means that the confidence of the image data itself is lower, which requires more reliance on the optical flow constraint, so $\lambda$ can be taken larger value; otherwise, a smaller value can be used.

The derivative of Formula (10) is obtained for $u$ and $v$ respectively. When the derivative is zero, the formula takes the extreme value:

$$2I_x (I_x u + I_y v + I_z) + 2\lambda (u - \bar{u}) = 0$$

$$2I_y (I_x u + I_y v + I_z) + 2\lambda (v - \bar{v}) = 0$$  \hspace{1cm} (10)

Using the relaxed iterative method to solve Formula (11), the iterative equation is:

$$u^{(k+1)} = u^{(k)} - I_x \frac{I_x u^{(k)} + I_y v^{(k)} + I_z}{\lambda^2 + I_x^2 + I_y^2}$$

$$v^{(k+1)} = v^{(k)} - I_y \frac{I_x u^{(k)} + I_y v^{(k)} + I_z}{\lambda^2 + I_x^2 + I_y^2}$$  \hspace{1cm} (11)

In the process of solving Formula (12), the time and space differentiation of gray scale pair should be taken into account. If the subscripts $i$, $j$, and $k$ correspond to $x$, $y$, and $t$, respectively, then the three partial derivatives can be replaced by first-order differences, and the corresponding filter coefficients are [-1, 1; -1, 1]. Formula (13) uses the average of the first-order difference results of the two frames before and after to approximate the temporal and spatial differentiation of the gray pair.

$$I_x = \frac{1}{4} (I_{i,j,k+1} + I_{i,j+1,k} + I_{i,j+1,k+1} + I_{i+1,j+1,k+1}) - \frac{1}{4} (I_{i,j,k} + I_{i,j,k+1} + I_{i,j+1,k+1} + I_{i+1,j+1,k+1})$$

$$I_y = \frac{1}{4} (I_{i,j+k+1} + I_{i+1,j+k} + I_{i+1,j,k+1} + I_{i+1,j+1,k+1}) - \frac{1}{4} (I_{i,j,k+1} + I_{i,j+1,k} + I_{i+1,j+1,k+1} + I_{i+1,j+1,k+1})$$

$$I_t = \frac{1}{4} (I_{i,j+k+1} + I_{i+1,j+k} + I_{i+1,j,k+1} + I_{i+1,j+1,k+1}) - \frac{1}{4} (I_{i,j,k} + I_{i,j+1,k} + I_{i+1,j+1,k} + I_{i+1,j+1,k+1})$$  \hspace{1cm} (12)
4.2. Implementation of optical flow method

The optical flow method is used to detect moving vehicles. First, the program reads video frames and converts the read video frames into grayscale images. Then, the optical flow calculation is used to assign a speed vector to each pixel in the image. Form a motion vector field in the image, and then analyze the velocity vector characteristics of each pixel in the image. If there is no moving vehicle in the image, the optical flow vector continuously changes in the entire image area. Otherwise, the motion of the moving vehicle and the background are relative. Different speeds cause discontinuous changes in the optical flow vector across the entire image area, thereby detecting the position of the moving vehicle, and finally thresholding the amplitude of the optical flow field to obtain a binary image. A location with large amplitude indicates that there are moving vehicles. The four operations of morphological filtering are combined to process the binary image, statistics the position and area of the moving vehicle, determine whether the area is a moving vehicle based on the area ratio, area ratio is too small is considered to be the information such as noise, this loops processing until the video processing ends.

Figure 11. The 37th frame  Figure 12. The optical flow vector  Figure 13. The detection result

Figure 14. The 92nd frame  Figure 15. The optical flow vector  Figure 16. The detection result

Figure 11 is the 37th frame of the video, Figure 12 is the representation of the optical flow vector on the moving vehicle, Figure 13 is the detection result, Figure 14 is the 92nd frame of the video, and Figure 15 is the representation of the optical flow vector on the moving vehicle. Figure 16 is the detection result. According to the test results, it can be found that the optical flow method can detect moving vehicles, but can only obtain the contour edge information of moving vehicles. There are large voids inside the moving vehicles. This method is more sensitive to light and has poor anti-noise ability, the real-time and practicability of moving vehicle detection cannot be guaranteed, so it is necessary to study improved algorithms to improve the effectiveness and real-time of the detection results of optical flow method.

5. Conclusion

The inter-frame difference method operates on frames in a video image sequence, by two or three adjacent frame subtraction, in order to obtain the contour of a moving vehicle. This method is simple, has a small amount of calculation, and is easy to optimize, but it needs to choose a suitable threshold. It can only get the contour edge information of the moving vehicle. There are isolated points and a few disconnected areas inside the contour, and there are large voids inside the moving vehicle. The background difference method uses the current frame image and the background image to perform a differential operation to detect for a moving vehicle, when the background image changes slightly for a long time or a large change occurs within a short period of time, the pre-stored background image needs to be updated. This method has a large amount of calculation, high complexity, and can detect a more complete moving vehicle, not only includes the contour information of the moving vehicle, but also the connected area inside the moving vehicle, but this method is more sensitive to light changes
and easily detects more noise; the optical flow method uses different speed vectors formed by the moving vehicle Velocity vector based on background, from which the position of moving vehicle can be detected, Horn-Schunck optical flow method enough to detect moving vehicles, but can only get the contour edge information of moving vehicles. There are large voids inside the moving vehicle. This method is more sensitive to light and has poor anti-noise ability, which cannot guarantee the real-time and practicality of moving vehicle detection.

In short, with the deepening of research on moving vehicle detection technology, many technical problems have been solved. But there are still some issues that need further research, such as: complex background problems, micro-moving target detection problems, moving vehicle shadow problems, moving vehicle occlusion problems, etc. It is believed that with the gradual resolution of these problems, moving vehicle detection technology will be more and more widely applied.

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