Image tracking and matching algorithm of semi-dense optical flow method

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Abstract: The traditional optical flow method is based on the assumption of spatial consistency of the optical flow field. It is easy to reduce the tracking quality and even lead to the loss of target tracking in the areas of image feature missing, boundary and occlusion. A semi-dense optical flow method is proposed to realise stable tracking of image features. Firstly, the feature points are preserved by calculating the pixel points with large change of pixel gradient in the image; Secondly, according to the principle of grey level invariance, the grey level difference function between the corresponding feature points of adjacent frames is constructed; Finally, the gradient descent principle is used to optimise the grey difference function and realise the accurate matching of feature points of adjacent frames. The results show that compared with the traditional LK optical flow method, this algorithm can effectively improve the feature tracking capability, and at the same time can effectively retain the useful information in the image. Compared with the traditional feature point matching method, the algorithm presented in this paper has an efficient operation rate.

Keywords: optical flow method; half dense; image processing; feature tracking; image matching.


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1 Introduction

With the development of intelligence, computer vision has become a research hotspot, among which image matching as the basis of computer vision is particularly important. Traditional image matching is mainly divided into two categories: one is based on feature points (Liu et al., 2007), and the other is based on the assumption of grey level invariance (Zhong et al., 2008). The image matching methods based on feature points were mainly based on SIFT (Lowe, 1999, 2004), SURF (Bay, 2004), and the efficient ORB FAST and Rotated BRIEF extraction algorithm proposed by Rublee et al. (2012). ORB algorithms are 100 times faster than SIFT and 10 times faster than SURF algorithms. Although the ORB feature extraction algorithm has an overall excellent performance in image matching and image positioning (Zeng et al., 2017), it also has obvious disadvantages in some aspects (Zhao et al., 2020): (1) When using feature points, we only pay attention to the information of feature points, and tend to ignore all the information except feature points, and discard most of the image information that may be useful. (2) When the camera moves to the missing feature, the number of feature points often decreases sharply, leading to a small number of correctly matched feature points, which greatly reduces the accuracy and stability of image matching. (3) When ORB feature points are used for image matching, it is often necessary to calculate the descriptors of the feature points. However, the calculation of descriptors requires a lot of time and computing resources. The extraction process of feature points is slow.

The method of image matching based on the assumption of constant grey level is mainly optical flow method. In the optical flow method, it is not necessary to know the relative relation between features, but to solve the corresponding relation between them by minimising the luminosity error, and to estimate the motion of features according to the brightness information of pixels. Therefore, the motion state of the camera cannot be estimated in the case of feature missing is avoided. At the same time, optical flow method does not need to compute feature descriptors, which can save a lot of computing resources.

At present, the main optical flow methods can be divided into two categories: One is the sparse optical flow method, represented by the optical flow method of Lucas and Kanade (1997). The other is the dense optical flow method, represented by the Bruhn et al. (2017) optical flow method. The LK optical flow method, this algorithm can effectively improve the feature tracking ability, ensure the important information in the image is not lost, and improve the operation rate at the same time.

2 Principle of semi-dense optical flow method

2.1 Semi-dense optical flow algorithm

Optical flow method is a fast algorithm with good performance. It is widely used in image feature matching. However, the current optical flow method has some defects. LK optical flow method can quickly achieve feature extraction and tracking. However, it only extracts feature points of the image, while other important information in the image is discarded. As a result, the data obtained by LK optical flow method can only obtain sparse results in subsequent processing. HS optical flow method requires the whole image to be processed by optical flow method, which consumes computing resources and a lot of time. In the proposed half dense optical flow image tracking matching algorithm, the image feature selection stage, in between the pixel and the surrounding neighbourhood grey gradient changes as a benchmark to determine the feature points, according to the principle of grey level unchanged and gradient descent principle calculation feature point matching relation between the precision and rapid matching between the feature points. The algorithm presented in this paper can improve the operation rate and reduce the operation time while retaining the image information. It is a fast, accurate and stable image matching algorithm. The process is shown in Figure 1.

2.2 Selection of semi-dense feature points

The traditional sparse optical flow method mainly uses the extraction of ORB feature points as the basis for matching, but the extraction of ORB feature points in scenarios with
not rich feature information is likely to cause loss. At the same time, in the scene with rich features, ORB feature points intelligently extract a small amount of information in the image, resulting in the loss of a large amount of information in the image. In this paper, in order to make the system run as stably as possible and save as much information in the image as possible, semi-dense feature points are selected as the basis of image feature matching to achieve easier image feature extraction and preservation. The selection of semi-dense feature points is mainly based on the change of grey level gradient, and the region with large grey level change is selected as the feature region. The specific implementation process is as follows:

1) Firstly, each pixel in the grey scale of the source image is traversed, and the grey scale points within the edge range of 10 pixels are eliminated.

2) A two-dimensional vector is constructed to store the grey change value of the adjacent pixels around each selected pixel. Where, the grey change value around each pixel is calculated by Formula 1:

\[
\delta_{(i,j)} = \begin{bmatrix}
\text{grey}_{(i,j)-1} - \text{grey}_{(i,j)},
\text{grey}_{(i-1,j)} - \text{grey}_{(i-1,j)-1}
\end{bmatrix}^T
\]  

(1)

3) The threshold value is set to judge whether the two-norm of the grey gradient vector is greater than the threshold value. When the two-norm of the gradient vector is greater than the threshold value, the feature region is retained as the feature region tracked by the optical flow method; otherwise, the region is eliminated and the next region is calculated.

Figure 1 Flowchart of semi-dense optical flow algorithm

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2.3 Matching of semi-dense feature points

In the input image data, we can consider that the grey scale of the image feature points between adjacent frames is unchanged (Bradski and Kaehler, 2014), and the frames are continuous. We can calculate the motion information between frames according to the corresponding relationship between these frames, so as to realize the tracking of image features (Gibson, 1950). Assume that the pixel grey value corresponding to pixel \((x, y)\) at the time \(t\) of the first frame image is \(I(x,y,t)\). After \(dt\) time, the pixel moves to the second frame image, and the grey value changes to \(I(x+dx,y+dy,t+dt)\). According to the principle of grey level invariance between adjacent frames (Bouguet, 1999), it can be obtained as follows:

\[
I(x,y,t) = I(x+dx,y+dy,t+dt)
\]

(2)

Taylor expansion of formula (2) can be obtained as follows:

\[
I(x+dx,y+dy,t+dt) = I(x,y,t) + \frac{\partial I}{\partial x} dx + \frac{\partial I}{\partial y} dy + \frac{\partial I}{\partial t} dt
\]

(3)

Since the grey level of feature points between moving frames of the image is constant, the reciprocal of the grey level function to any variable is zero, so we can get:

\[
\frac{\partial I}{\partial x} dx + \frac{\partial I}{\partial y} dy + \frac{\partial I}{\partial t} dt = 0
\]

(4)

The identity transformation can be obtained as follows:

\[
\frac{\partial I}{\partial x} dx + \frac{\partial I}{\partial y} dy = -\frac{\partial I}{\partial t}
\]

(5)

where \(\frac{dx}{dt}\) represents the moving speed of pixels on \(x\) axis, and \(\frac{dy}{dt}\) represents the running speed of pixels on \(y\) axis, denoted as: \(u,v\). Therefore, the partial derivative is the gradient of the image in the direction of \(x\) and \(y\), which can be written in the form of matrix:

\[
\begin{bmatrix}
I_x, & I_y
\end{bmatrix} \cdot \begin{bmatrix}
u \\
v
\end{bmatrix} = -I,
\]

(6)

In equation (5), we need to solve the parameters of \(u,v\), that is, the moving speed of \(x\) and \(y\) should be required. Select a window with the size of \(w\times w\) and form a super-linear system of equations with pixels in the selected window. The following equations are obtained:

\[
A = \begin{bmatrix}
I_x, & I_y
\end{bmatrix}, \quad b = \begin{bmatrix}
I_1 \\
\vdots \\
I_w
\end{bmatrix}
\]

(7)
According to the above equation (7), the least squares algorithm is used to solve the equation set, and the value of $u$, $v$ parameter can be obtained, so as to realise the moving speed of image feature points and realise the purpose of image feature matching.

3 Experimental results and analysis

In order to verify the effectiveness of the algorithm in this paper, the ORB feature point method, the LK optical flow method and the algorithm in the standard data set images were used for comparative analysis of the amount of image information extraction and time. According to the experimental results, the following data can be obtained.

Figures 2(a), 2(c) and 2(e) represent the image matching results of ORB feature points, respectively; Figures 2(b), 2(d) and 2(f) represent the image tracking results achieved by the algorithm in this paper, respectively. Through three groups of image matching experiment results, it can be seen that although ORB feature point method can carry out image matching, it can only save the information of feature points, but cannot save the image information. At the same time, we can also see that ORB feature point matching has a large number of mismatched points. As can be seen from the algorithm results in this paper, the image contains a large amount of useful information, which ensures the maximum retention of image information and the stable and efficient tracking of image features.

In the above three groups of image tracking experiments, data of ORB feature point extraction and this algorithm can be obtained as shown in Table 1.

![Figure 2 Experimental results of ORB feature point method and the algorithm in this paper](image)

<table>
<thead>
<tr>
<th>Figure 2</th>
<th>Number of ORB algorithm checks</th>
<th>ORB algorithms are time consuming /s</th>
<th>Each feature point takes time /ms</th>
<th>In this paper, the algorithm detects the number</th>
<th>The algorithm in this paper takes time /s</th>
<th>Each characteristic area takes time /ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) / (b)</td>
<td>500</td>
<td>0.37</td>
<td>0.74</td>
<td>14,036</td>
<td>2.28</td>
<td>0.1624</td>
</tr>
<tr>
<td>(c) / (d)</td>
<td>500</td>
<td>0.39</td>
<td>0.78</td>
<td>14,327</td>
<td>2.76</td>
<td>0.193</td>
</tr>
<tr>
<td>(e) / (f)</td>
<td>500</td>
<td>0.37</td>
<td>0.74</td>
<td>23,261</td>
<td>4.084</td>
<td>0.175</td>
</tr>
</tbody>
</table>
According to the analysis in the above table:

1) The number of feature tracking using the algorithm in this paper is dozens of times more than that detected by ORB feature method, which proves that the algorithm in this paper can well retain image information.

2) According to the table analysis, it can be seen that the algorithm in this paper takes 0.1624, 0.193 and 0.175 milliseconds, respectively to calculate each feature area of each group of images, and the ORB feature point method takes 0.74, 0.78 and 0.74 milliseconds, respectively to calculate each feature point of each group of images. It is concluded that the algorithm in this paper runs much faster than ORB feature point method.

Figures 3(a), 3(c) and 3(e), respectively represent the image tracking results achieved by the LK optical flow method, and Figures 3(b), 3(d) and 3(f), respectively represent the image tracking results achieved by the algorithm in this paper. Through three groups of image matching experiment results, it can be seen that the LK optical flow method can better realise feature tracking, but it can only extract feature points in the image, and cannot retain useful information in the image. As can be seen from the algorithm results in this paper, the image contains a large amount of useful information, which ensures the maximum retention of image information and the stable and efficient tracking of image features.

In the above three groups of image tracking experiments, data extracted from the LK optical flow method and the algorithm presented in this paper can be obtained as shown in Table 2:

**Table 2** Image feature loss rate and time consuming

<table>
<thead>
<tr>
<th>Figure 3</th>
<th>LK algorithm number of detection</th>
<th>LK algorithm lost number</th>
<th>LK algorithm loss rate %</th>
<th>LK algorithm time consuming /s</th>
<th>In this paper, the algorithm detects the number</th>
<th>The algorithm in this paper loses the number</th>
<th>In this paper, the algorithm loss rate %</th>
<th>The algorithm in this paper takes time /s</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) / (b)</td>
<td>2069</td>
<td>212</td>
<td>10.25</td>
<td>0.53</td>
<td>14,036</td>
<td>12</td>
<td>0.085</td>
<td>2.28</td>
</tr>
<tr>
<td>(c) / (d)</td>
<td>1781</td>
<td>20</td>
<td>1.12</td>
<td>0.19</td>
<td>14,327</td>
<td>233</td>
<td>1.63</td>
<td>2.76</td>
</tr>
<tr>
<td>(e) / (f)</td>
<td>3476</td>
<td>233</td>
<td>6.70</td>
<td>0.47</td>
<td>23,261</td>
<td>1157</td>
<td>4.97</td>
<td>4.084</td>
</tr>
</tbody>
</table>
According to the analysis in the above table:

1) The number of feature tracking using this algorithm is several times more than that of LK optical flow method, which proves that this algorithm can well retain image information.

2) When using this algorithm for feature tracking, the image feature loss rate is all at a low level, which proves that this algorithm has better stability and higher tracking quality than the LK optical flow method.

3) According to the table analysis, it can be seen that the algorithm in this paper takes 0.1624, 0.193 and 0.175 milliseconds, respectively to calculate each feature area of each group of images, and the LK optical flow method takes 0.256, 0.1066 and 0.135 milliseconds respectively to calculate each feature point of each group of images. It is proved that the algorithm in this paper has a higher operational speed than the LK optical flow method in some scenes, and the same as the LK optical flow method in other scenes.

In conclusion, the overall performance of the algorithm in this paper is excellent, which can fully extract useful information from the image and realise stable feature tracking on the premise of ensuring the operation rate.

4 Conclusion

When LK optical flow method conducts feature tracking, a large amount of useful information in the image is lost, which easily leads to insufficient image information in the subsequent processing. At the same time feature tracking stability is poor, easy to cause feature loss. ORB feature point algorithm not only loses a lot of image information during feature matching, but also consumes a lot of time to calculate feature descriptors. To resolve above problems, this paper put forward the half dense optical flow method of image tracking matching algorithm, the algorithm will LK optical flow method FAST corner detection for image grey gradient detection, based on the gradient of the larger image tracking area to realise optical flow method, can effectively keep the useful information in the image, at the same time improve the quality of image matching feature area, and ensure the operation rate. Through the comparison experiment with ORB feature points and LK optical flow method, we can conclude that this algorithm can effectively improve the feature tracking capability, ensure the important information in the image is not lost, and ensure the operation rate and stability of the algorithm.

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