Improved NCC Stereo Matching Algorithm

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Abstract. In the binocular stereo vision system, image matching is a key step to realize 3-D reconstruction. So many methods were proposed to solve the problem, among which the normalized cross correlation (NCC) algorithm is usually used because of its advantages such as high robust and precision, but its computing process is so complicated that difficult to apply on line. Therefore, the integral image and squared integral image are introduced, an improved NCC algorithm is proposed. The summation operation of pixels’ value in a certain region will be reduced greatly by using the algorithm, that is, it only requires to operate additions and subtractions of four pixels’ value. Simultaneously, mismatch areas in the reference image are eliminated to decrease the search range. The improved NCC algorithm not only guarantees the match quality but also improves the speed of execution greatly. Through the simulation experiment, the validity of it is verified.

Introduction

Binocular stereo vision is an important branch of computer vision in recent years, it has been a research focus. It is applied in many fields such as robot navigation and control, meters detection for micro operation system, etc. The realization process of binocular stereo vision technology includes image acquisition, camera calibration, feature extraction, image matching and 3-D reconstruction. [1]

In this process, the image matching is a key step and precondition to restore three-dimensional scene, its objective is essentially to find similarity of two images. Binocular stereo vision image matching is a kind of technology to find out the correspond relations of each pixel in two images obtained by the two level cameras, then get their best visual disparity values and disparity map. [2]

Usually, image matching methods can be divided into three kinds, that is feature matching [3], phase matching [4] and area matching [5]. Feature matching method is a class of algorithms to match images based on the extracted feature parameters, its advantages are small calculation and fast speed, but it is difficult to obtain dense disparity map because of matching results affected by image feature's sparsity. Phase matching method is developing recently, it can reflect the structure information of the signals and restrain the high frequency noise of the image; it applies to parallel process phase singularity and phase winding problems. Region matching method is based on the correlation of gray information between local windows. The commonly used matching similarity measure functions include NCC (Normalized Cross Correlation), SSD (Sum of Absolute Differences) and SAD (Sum of Squared Differences). Among them, NCC algorithm is used commonly, it has the advantages of high precision, strong robustness [6], but speed is its weakness, so online application is restricted. In the following, an improved NCC algorithm is proposed by introducing squared integral image.

Image and Square Integral Image

Integral Image Integral

Integral image theory was proposed by Viola P and Jones M in 2001 [7]. Integral image is an image representation, it is mainly used to compute the sum of image gray level of window area, it has a wide
range of applications because it is fast\cite{8}. Supposed the gray value of any pixel \((i, j)\) is \(ii(i, j)\) in the integral image, it can be represented as follows

\[
ii(i, j) = \sum_{x \leq i, y \leq j} i(x, y)
\]  

(1)

where \(i(x, y)\) is the gray value of the pixel \((i, j)\) in the source image. Let \(s(i, j)\) as the integral of gray values at \(i\) row and \(j\) column in the source image. There is

\[
s(i, j) = s(i, j-1) + i(i, j) ; \ ii(i, j) = ii(i-1, j) + s(i, j)
\]  

(2)

when equation (2) is used to program, the image should be extended one row and one column to ensure \(i-1 > 0\) and \(j-1 > 0\).

Given a rectangular window in the original image, its vertices are represented by \(A, B, C\) and \(D\) in turn. If we use integral image to calculate its grey, no matter how large the rectangular window area is, it only need three addition and one subtraction operations, that is

\[
S = p(D) + p(A) - p(B) - p(C)
\]  

(3)

where \(S\) represents gray value of the rectangular window area, \(p(A), p(B), p(C)\) and \(p(D)\) are grey value of rectangular window area respectively.

**Square Integral Image**

In order to obtain square sum of all pixels gray level quickly, a square integral image is introduced based on integral image\cite{8}. In practice, square integral image is stored in matrix form, so any point \(Pii(i, j)\) in the square integral image can be expressed by

\[
Pii(i, j) = \sum_{x \leq i, y \leq j} i^2(x, y)
\]  

(4)

here \(i^2(x, y)\) is square of grey value of point \((x, y)\). Let \(Ps(i, j)\) denotes gray square integral of \(i\) th line and \(j\) th column. According to equation (2), there have

\[
Ps(i, j) = Ps(i, j-1) + i^2(i, j) ; \ Pii(i, j) = Pii(i-1, j) + Ps(i, j)
\]  

(5)

Then using equation (3), square sum of grey values in a window can be calculated. This method has the advantages of simple operation, it can greatly reduced amount of computation.

**NCC Algorithm and Its Improvement**

**The NCC Matching Algorithm**

The objective of image matching is to find similarity of two images essentially. Firstly, select any match point in the right image, calculate \(disMax + 1\) normalization coefficients with all parallax \(d \in [0, disMax]\). Secondly, select the corresponding point of the max normalization coefficient as the optimum match point in the left image, the point's disparity \(d\) will be optimum. If the size of the selected image is \(M \times N\) and the size of the model is \(m \times m\), then the normalized cross-correlation can be represented as follows\cite{9}:

\[
Ncc(d) = \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} (I_R - \bar{I}_R) \sum_{i=1}^{m} \sum_{j=1}^{m} (I_L - \bar{I}_L)}{\sqrt{\sum_{i=1}^{m} \sum_{j=1}^{m} (I_R - \bar{I}_R)^2 \sum_{i=1}^{m} \sum_{j=1}^{m} (I_L - \bar{I}_L)^2}}
\]  

(6)
where

\[ I_R = I_R(x+i, y+j); \quad \bar{I}_R = \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} I_R}{m^2}; \quad I_L = I_L(x+i, y+j+d); \quad \bar{I}_L = \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} I_L}{m^2} \]  

According to equation (6), when correlation coefficients are calculated, it needs to compute mean values of all window regions. So NCC algorithm has many disadvantages such as high complexity, long time-consumption, poor real-time.

**The Improve NCC Algorithm**

In the NCC algorithm, it needs to calculate the pixels' mean values of all window regions. When we want to calculate a parallax, it needs to have \(6(m \times m - 1)\) times additions, \(4(m \times m - 1)\) times subtractions, \(2(m \times m - 1)\) times powers, 2 times multiplications, 3 times division and one evolution. Furthermore, the amount of calculation will be changed with the window size \(m \times m\), the larger the template windows, the more time is consumed. In order to reduce the amount of calculation, let equation (6) simplified before the mean values of the normalized cross correlation coefficient are operated. Then equation (6) can be described by

\[ Ncc(d) = \frac{S_{RL} - S_{R}S_{L}/m^2}{\sqrt{(S_{RR} - S_{R}S_{L}/m^2)(S_{LL} - S_{L}S_{L}/m^2)}} \]  

where

\[ S_{RL} = \sum_{i=1}^{m} \sum_{j=1}^{m} (I_R I_L) \]  

\[ S_{R} = \sum_{i=1}^{m} \sum_{j=1}^{m} I_R; \quad S_{L} = \sum_{i=1}^{m} \sum_{j=1}^{m} I_L; \quad S_{RR} = \sum_{i=1}^{m} \sum_{j=1}^{m} I_R^2; \quad S_{LL} = \sum_{i=1}^{m} \sum_{j=1}^{m} I_L^2 \]  

here, equation (9) can reduce the calculation by using the convolution, while equation (10) can be used to calculate the value of the window regions with integral and square integral image, so the sum of the region gradation values can be calculated by the addition or subtraction operation of the four vertices. Based on the above analysis, it only requires 8 times additions, 7 times subtractions, 4 times division, 4 times multiplications, one evolution and convolution for each disparity value. Furthermore, the amount of calculation will not be changed with the window size, it reduces the calculation complexity and improves computing speed greatly.

In the binocular stereo matching, because of existing disparity between two images, it can’t find matching points in the left image for many right boundary points in the right image, and the template window has a certain size, thus the actual ranges of matching area are \(y \leq N - dispMax + m\), \(x \leq M - m\). To eliminate those areas which can’t be matched not only ensures that the matching point can be searched completely but also reduces the matching time and improves the search efficiency.

Through the previous analysis, the improved NCC algorithm has many advantages by introducing the integral image and square integral image. Its implementation steps are as follows:

**Input:** The reference image \(I_R\) gathered by the right camera, the real-time image \(I_L\) gathered by the left camera.

**Output:** The disparity matrix, the disparity map.

Step 1: To calculate corresponding integral image and squared integral image \(S_R, S_{RR}\) and \(S_L, S_{LL}\) of \(I_R\) and \(I_L\) respectively, and give initial values of x and y.

Step 2: Using the equation (3) to obtain template window within the parallax range, then search grey values’ sum and square sum of the covered area by template window and search window.
Step 3: To calculate $S_{RL}$ including in the template window and search window by matrix convolution.

Step 4: Using the equation (8) to calculate a correlation coefficient, repeat steps 2-3 until the condition of $y \leq N - \text{dispMax} + m$ & $x \leq M - m$ is satisfied. To output the disparity matrix and map.

**Experiments and Analysis**

The hardware of this experiment is a PC, the CPU of which is Pentium(R) Dual-Core, and its memory is 1.96GHz. The software is MATLAB 2011b.

**Standard Test Image Experiment and Analysis**

The experiment adopted international standard test image Teddy shown in Figure 1, the real disparity map of Teddy is shown in Figure 2. The obtained disparity maps by NCC algorithm and improved NCC algorithm are shown in Tab.1.

![Right image](image1.png) ![Left image](image2.png) ![Teddy disparity map](image3.png)

Figure 1. International general test image Teddy. Figure 2. The real disparity map of Teddy.

Can be seen from Tab.1, when NCC algorithm is used, there is no match points in the right border region, it increased the computation time and reduced real-time performance. When improved NCC is used, all those mismatch points are eliminated, it improves computational efficiency. By comparing with the real disparity map in Fig.2, the improved NCC algorithm has better accuracy and robustness.

| Window size | NCC | Improved NCC |
|-------------|-----|--------------|
| 5×5         | ![NCC 5×5](image4.png) | ![Improved NCC 5×5](image5.png) |
| 7×7         | ![NCC 7×7](image6.png) | ![Improved NCC 7×7](image7.png) |
| 9×9         | ![NCC 9×9](image8.png) | ![Improved NCC 9×9](image9.png) |

Table 1. The obtained disparity map by two algorithms.

In Tab.2, time consumption contrast of NCC and improved NCC are given. It shows that the improved NCC algorithm consumes less time than the NCC algorithm. When $m \geq 9$, the improved NCC algorithm consumes a significant reduction in the time, and the time-consumption is hardly affected by the window size.

| Window size | Time consuming | Time decrease |
|-------------|----------------|---------------|
| 7×7         | 83.3s          | 80.5s         | 3.4%          |
| 9×9         | 149.1s         | 83.4s         | 44%           |
| 11×11       | 231.8s         | 86.1s         | 62.8%         |

Table 2. Time consumption contrast of two algorithms.
Collected Image Experiment and Analysis

This experiment adopts the Bumblebee-2 stereo camera produced by Point Grey company to capture two real images, which are corrected is shown in Figure 3. To select the right camera image as the reference image, the left image is regarded as real-time image. The obtained disparity maps by NCC algorithm and improved NCC algorithm are shown in Figure 4.

![Image 1](Image 1)  ![Image 2](Image 2)  ![Image 3](Image 3)  ![Image 4](Image 4)

(1) Right image  (2) Left image  (1) NCC algorithm  (2) Improved NCC

Figure 3. The experiment images.

Figure 4. The obtained disparity maps of two algorithms.

Time consumption contrast of NCC and improved NCC are given in Tab.3. The results show that when the window template size is larger, the time consumption is less. Through the experiment, the superiority of the improved NCC algorithm is verified.

Table 3. Time consumption contrast of two algorithms.

| Image size | Window size | Time consuming | Time decrease |
|------------|-------------|----------------|---------------|
|            |             | NCC            | Improved NCC  |               |
| 480×640    | 7×7         | 397.967s       | 230.014s      | 42%           |
| 480×640    | 9×9         | 619.967s       | 235.284s      | 62%           |
| 11×11      | 894.116s    | 260.145s       |               | 71%           |

Conclusions

The paper proposed an improved NCC algorithm by introducing integral image and square integral image, which can reduce computation complexity and enhance matching speed. When the size of images and template windows is larger, the time-consuming is decreased more remarkably. Furthermore, it has better matching accuracy and robustness compared with the NCC algorithm.

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