Least Square Stereo Matching Based on Gradient Descent Method

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Abstract. Least Square method is widely adopted in stereo matching owing to it high precision, but the fact that transformation parameters is obtained by solving linear equations leads to the instability of its solutions and the process of matching oscillates and decreases convergence speed. To overcome this disadvantage, improve convergence speed and keep high precision, this paper provides gradient method to resolve stereo matching. The experiments show that the algorithm is valid and practical.

Keywords: Least Square; Stereo Matching; Gradient Descent Method

1 Introduction

Stereo matching is the most critical and most difficult step in binocular stereo vision. The difference from ordinary image registration is that stereo images are taken from two cameras at the same time or one camera at different time. So far, a lot of matching algorithms have been proposed. They are classified into two citatory: area based stereo matching [1, 2] and energy based stereo matching [3, 4, 5]. In area based stereo matching, disparities are obtained by local regions around the pixel under consideration, which is very suitable for texture regions, but produces poor results at discontinuities, especially for slope. The energy-based matching algorithm obtains disparities of corresponding points by minimizing the global energy function, which consists of the data term and the smooth term. The performance of the algorithms of the type is superior to local algorithms.

Stereo matching algorithm based on least square obtains disparities by minimizing the sum of the squared difference of gray levels of pixels between local regions around the pixels under consideration. The algorithm of this type assumes that disparities of corresponding points satisfies linear transformation, and then obtains transformation parameters by solving the over determined linear equations. This process will lead to the instability and fluctuation of the solution. In order to overcome this drawback, this paper employs the gradient descent method to solve the equations along the negative gradient direction to achieve transformation parameters, where the minimum of the equations is obtained.
2 Least square based on gradient descent for stereo matching

Stereo matching process is a process in which corresponding points are found in the left and right images. According to the assumption that the world is composed of Lambertian planes, that is, the gray values of corresponding points remains constant, the value of $F$ for corresponding points should be equal to 0, but in practice the value of $F$ is not equal to 0 because of image noises and lighting situation. The least square stereo matching based on gradient descent computes transformation parameters by finding local minimum of the objective function $F$ along the negative gradient direction. The objective function is given by

$$F = (r(x, y) - l(x', y'))^2$$  \hspace{1cm} (1)$$

$$\nabla F = \left[ \frac{\partial F}{\partial k_1}, \frac{\partial F}{\partial k_2}, \frac{\partial F}{\partial k_3}, \frac{\partial F}{\partial k_4}, \frac{\partial F}{\partial k_5} \right]^T$$ \hspace{1cm} (2)$$

$$\tilde{k} = k_0 - \lambda \nabla F$$ \hspace{1cm} (3)$$

Where $k$ denotes transformation parameters vector, $k_0$ is a initial value such as $[0 \ 1 \ 0 \ 0 \ 1]^T$. After several iterations, $\tilde{k}$ is found, on which the value of the objective function achieves the minimum. Then, the coordinate of corresponding points is computed by the computed linear transformation parameter. Furthermore, disparities are obtained.

In the actual iterative process, in order to make the matching process more stable and more robustness against noise, the objective function is applied in local windows around the pixels under consideration. The corresponding objective function and gradient direction are given by

$$F = \sum_{-w/2 \leq x < w/2} \sum_{-w/2 \leq y < w/2} [r(x + i, y + j) - l(r(x + i, y + j))]^2$$$$\nabla F = \sum_{-w/2 \leq x < w/2} \sum_{-w/2 \leq y < w/2} \left[ \frac{\partial F}{\partial k_1}, \frac{\partial F}{\partial k_2}, \frac{\partial F}{\partial k_3}, \frac{\partial F}{\partial k_4}, \frac{\partial F}{\partial k_5} \right]^T$$ \hspace{1cm} (4)$$

The specific steps of least square stereo matching method based on gradient descent are as follows:

1. For any pixel $(x, y)$ in the reference image and the initial corresponding point $(x', y')$ in the matching image, According to linear transformation parameters $k_0, k_1, k_2, k_3, k_4, k_5$, their relation is established by

$$x_2 = k_0 + k_1 x_1 + k_2 y_1$$
$$y_2 = k_3 + k_4 x_1 + k_5 y_1$$

In general, $k_0 = 0, k_1 = 1, k_2 = 0, k_3 = 0, k_4 = 1, k_5 = 0$ is chosen as the initial value of the transformation parameters.

2. Resample the window in the matching image by use of the interpolation algorithm according to the coordinates of corresponding point $(x_2, y_2)$. 

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(3) Solving the linear transformation parameters according to the gradient descent method.

(4) Compute residual error $F$, if $F$ is less than a threshold, then stop and go to (5), else go to (1).

(5) Compute $x_2$ and $y_2$ according to the linear transformation parameters.

(6) Compute a disparity according to $d = \sqrt{(x_i - x_2)^2 + (y_i - y_2)^2}$.

3 Result

In order to verify the effectiveness of the proposed algorithm, stereo images provided by Middlebury are adopted and mismatch rate, which is the rate of pixels of which the disparity is 1 less than the true disparity to all pixels, is used to evaluate its performance. This proposed algorithm is tested using Tsukuba, Sawtooth, Map and Venus in Middlebury. In this experiment, the window size $19 \times 19$ and the step size 0.1 are used. The experimental results are shown in Fig. 1.
4 Conclusion

In order to solve high computational complexity and slow convergence in the traditional least square stereo matching algorithm, we propose a least square stereo matching algorithm based on the gradient method. Experimental results shows that this proposed algorithm is a fast and effective algorithm and can obtain satisfactory results.

References