Fast Stereo Matching Algorithm using Edge Projection

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Abstract: We present fast stereo matching algorithm using edge projection. Traditional stereo matching algorithm uses 2D template for the search of corresponding point thus it requires huge the computational cost. In this paper, we reduce the 2D search problem into 1D using edge projection along vertical and horizontal direction inside the region of interest. Also, by accumulation of edge projection along vertical and horizontal direction, the edge projection within the region of interest could simply be obtained by just subtracting two values. Experimental results show that matching algorithm using edge projection also gives comparable discriminating power compared to that of using intensity.

Keywords: stereo, correspondence, edge projection, 3D

1. INTRODUCTION

3D reconstruction of a scene using cameras is heavily investigated topic in computer vision. This information can be used in various areas such as robot navigation, augmented reality and human computer interaction. Most approaches are based on stereo system. Recent interesting application such as image based rendering requires correspondence of each pixel. Typical approaches for 3D reconstruction using stereo systems as follows. First, each camera is calibrated using the correspondence between known 3d coordinates of calibration box and 2d image points of calibration points. Then rectified images are obtained that has correspondence on the same row. Finally, 3d reconstruction is done using the stereo correspondence.

In [1], 20 current stereo correspondence algorithms are investigated and evaluated using the same test data. They classify various stereo algorithms based on the general step involved in the stereo algorithm: matching cost computation, cost aggregation, disparity computation/optimization, and disparity refinement.

Local algorithms [2,3,4] assume that the disparity of a point depends only on intensity values within a predefined finite window. Typical matching costs in stereo correspondence are normalized cross-correlation [5,6,7], sum-of-squared differences (SSD), binary matching costs [8], and non-parametric measures such as rank and census transforms [9]. In this paper, we use edge projection values of a finite window for evaluating matching costs.

Fig. 1 shows various difficult areas for stereo correspondence such as depth discontinuity, occlusion, and homogenous region.

In this paper, we propose fast stereo matching algorithm using edge projection. First, edge magnitude of each pixel is calculated and this is accumulated along vertical and horizontal direction. In the matching phase, the edge magnitude of projection within the interesting region could be simply obtained by subtracting two edge values of boundary positions. Conventional area-based stereo matching algorithm uses the entire pixel in the current window, therefore the matching problem is inherently two-dimensional. By using edge projection, we could reduce the matching problem into one dimension. Through this, we can reduce the computational cost of stereo matching algorithm.

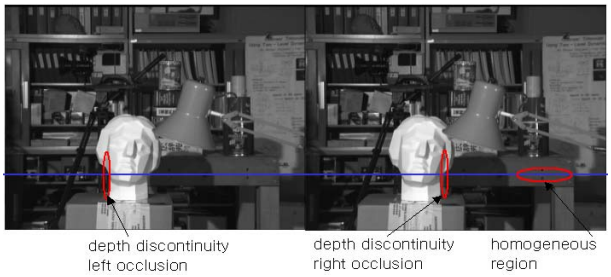


Fig. 1 Difficulty in stereo matching: depth discontinuity, occlusion and homogeneous region.

2. EDGE PROJECTION USING ACCUMULATION

Local area-based stereo matching algorithms [2,3,4] uses each pixel in the window for the cost evaluation so that the inherent problem is two dimensions. In this paper, we propose matching using two edge projections along horizontal and vertical directions within the local window. By this we can reduce the problem into one dimension and this is shown in Fig. 2. Also, edge has superior property in matching compared to that of using intensity where it can cope local illumination change.

First, we apply Sobel edge operator on the left and right image. For the horizontal edge projection, we accumulate edge magnitude in the row direction and for the vertical edge projection we accumulate edge magnitude in the column direction. After this accumulation of edge value along horizontal and vertical direction, we can simply obtain the edge projection value of arbitrary location by just subtracting two values accumulated edge values. This is shown in Fig. 3.

Let $E(i,j)$ as the edge magnitude at the pixel location of (i,j).

$$E(i,j) = \left|I_x(i,j)\right| + \left|I_y(i,j)\right| \quad (1)$$

where $\left|I_x(i,j)\right|$ and $\left|I_y(i,j)\right|$ represents the edge magnitude by Sobel operator in x and y direction. In this paper, 3X3 mask size is used. Accumulative edge magnitude of horizontal and vertical direction can be defined as

$$AE_x(i,j) = \sum_{k=0}^{i} E(k,j)$$
$$AE_y(i,j) = \sum_{k=0}^{j} E(i,k) \quad (2)$$

where $AE_x(i,j)$ and $AE_y(i,j)$ is accumulative edge magnitude along x and y direction.

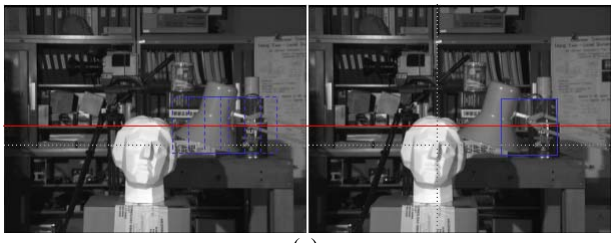
Using this accumulative edge, we can simply calculate the edge projection of ROI (Region Of Interest).

$$EP_x(i,j) = AE_x(i+h,j) - AE_x(i-h,j)$$
$$EP_y(i,j) = AE_y(i,j+h) - AE_y(i,j-h) \quad (3)$$

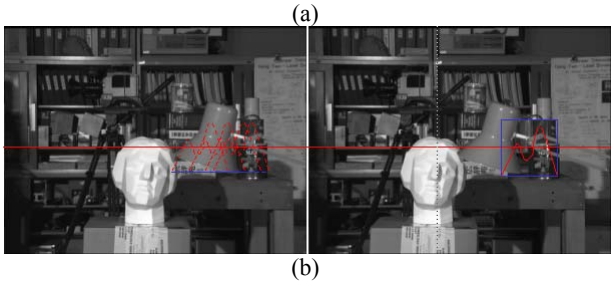
where $EP_x(i,j)$ is edge projection along row direction with height of $2h+1$ and $EP_y(i,j)$ is edge projection along column direction with width of $2h+1$.

As shown in Eq. (3), the edge projection of interesting points with arbitrary width can be obtained by simply subtracting accumulative edge of two points.

Fig. 4 shows the distribution of brightness value and edge projection along the horizontal direction White line in the image represents the corresponding row. Upper profile is the distribution of intensity and lower profile is the distribution of edge projection within predefined window. We can notice that the edge projection could be used in the stereo matching with comparable discriminating power of using intensity.

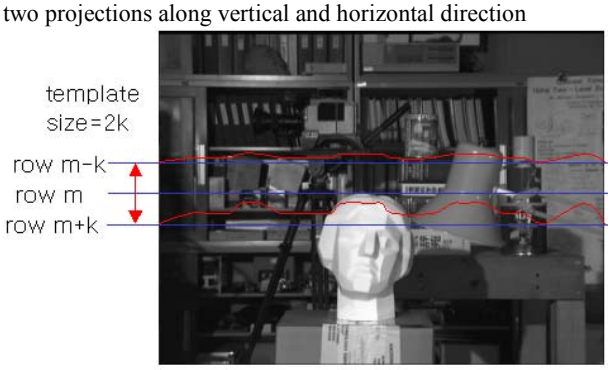


(a)

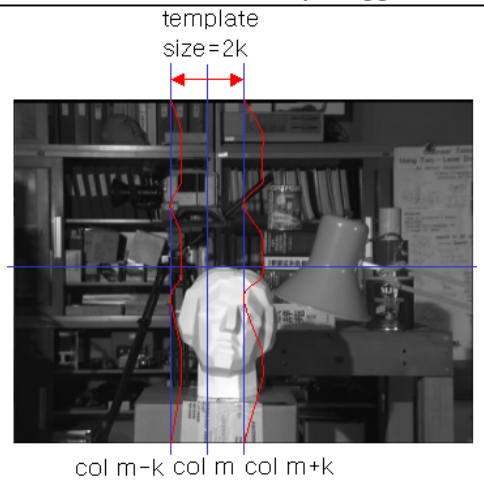


(b)

Fig. 2 Area-based stereo correspondence search in the horizontal direction (a) using intensity of each pixel (b) using two projections along vertical and horizontal direction



(a)



(b)

Fig. 3 Edge projection using accumulation (a) vertical edge projection (b) horizontal edge projection

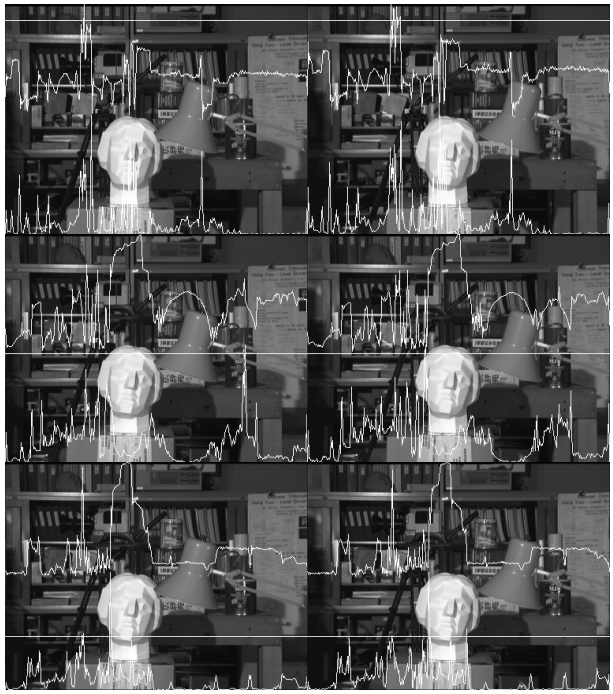


Fig. 4 Edge projection and brightness distribution along row. White line shows corresponding row in the image, and upper profile is the brightness and lower profile is edge projection (From left to right: left image and right image).

3. STEREO MATCHING USING EDGE PROJECTION

Local area-based stereo correspondence algorithms get the solution by finding the minimum cost along the search range. Sum of absolute difference (SAD) uses intensity value of each pixel within the local window as the matching cost. In this paper, we use edge projection value along two directions within the local window as the matching cost, and we call it as SAD_EP (Sum of Absolute Difference of Edge Projection).

SAD can be represented as

$$SAD(x,y,d)=\sum_{i,j=-n}^{n}\left|I^{l}(x+i,y+j)-I^{r}(x+i+d,y+j)\right| \quad (4).$$

where $I^{l}(x,y)$ and $I^{r}(x,y)$ is intensity value of left and right image at the location (x,y).

SAD_EP can be set as

$$SAD_EP(x,y,d)=\sum_{i=-n}^{n}\left|EP_{x}^{l}(x+i,y)-EP_{x}^{r}(x+i+d,y)\right|+\sum_{i=-n}^{n}\left|EP_{y}^{l}(x,y+i)-EP_{y}^{r}(x,y+i+d)\right| \quad (5).$$

where $EP_{x}^{l}(x,y)$ and $EP_{x}^{r}(x,y)$ is edge projection value of left and right image at the location (x,y). According to Eq. (4) and Eq. (5), the search problem has reduced from 2-dimension into 1-dimension.

To further reduce the computational cost, we adopt coarse-to-fine search using image pyramid. At the top level of pyramid, disparity value of each pixel is searched using Eq. (5) and this is propagated into next fine level of pyramid where the search is done near the position found in the upper level of pyramid.

4. EXPERIMENTAL RESULTS

In the experiment, we evaluate the accuracy of correspondence using image set with true disparity map and also compares the computational cost between proposed algorithm and conventional SAD.

Fig. 5 shows Tsukuba stereo image that provide true disparity map and it is available through web site in [1]. The size of Tsukuba image is 288x384 and the disparity map is shown in Fig. 6(a). Max disparity is set as 16.

Fig. 6 shows estimated disparity map by SAD and proposed algorithm. Window size used in the experiment is 7x7, 9x9 and 11x11. Also, matching using one edge projection within window is tested. Computation is done under Intel Pentium 4 CUP 2.00 GHz with 448MB RAM.

SAD and proposed algorithm gives smoothed disparity map near the depth discontinuity. Also both gives large error in the homogenous region. Table 1 shows the processing time and accuracy of estimated disparity. The accuracy of disparity is obtained by comparing with true disparity. Proposed stereo matching algorithm using edge projection within local window could achieve large computational cost reduction while keeping the matching quality comparable to SAD.

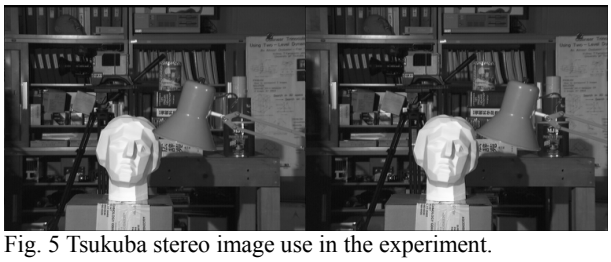


Fig. 5 Tsukuba stereo image use in the experiment.

5. CONCLUSION

In this paper, we proposed stereo matching algorithm using edge projections within local window. Local area-based stereo matching algorithm could be reduced from 2-dimension into 1-dimension using edge projection while keeping the matching quality comparable to SAD.

Future research direction is improving the accuracy near the depth discontinuity using edge projection.

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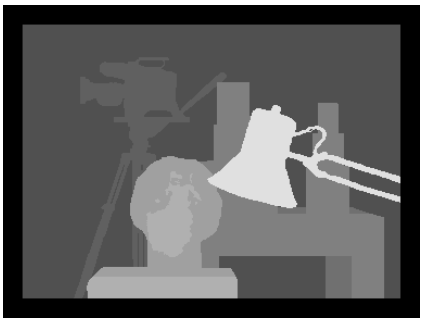
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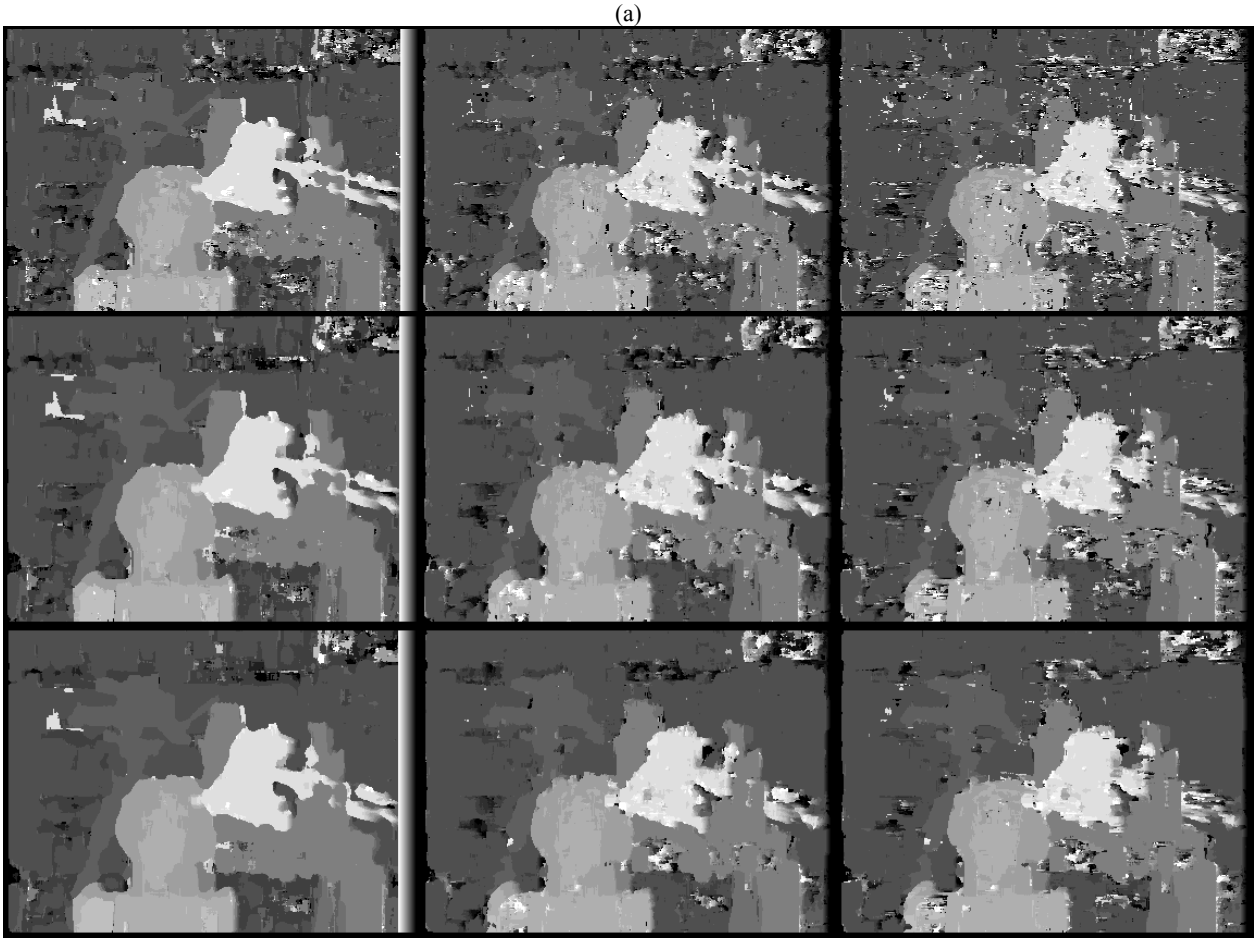
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(a)



(b)

Fig. 6 Experimental results of disparity map (a) true disparity (b) estimated disparity (first column: result by SAD (Sum of Absolute Difference), second column: result by using two edge projection, third column: result by using one edge projection, and mask size is first row: 7x7, second row: 9x9, third row: 11x11)

Table 1 Processing time and accuracy of estimated disparity (SAD: Sum of Absolute Difference, SAD_EP: Sum of Absolute Difference of two Edge Projections, SAD_EP_X: Sum of Absolute Difference of Edge Projection along X, image size: 288x384)

Mask Size	Method	Time [sec]	abs(disparity error)>0	abs(disparity error)>1
7X7	SAD	1.83	41.7	19.0
	SAD_EP	0.807	38.8	22.6
	SAD_EP_X	0.340	40.5	25.2
9X9	SAD	3.18	38.0	16.0
	SAD_EP	1.03	34.9	20.2
	SAD_EP_X	0.451	35.6	21.3
11X11	SAD	4.96	35.6	14.3
	SAD_EP	1.26	32.5	18.8
	SAD_EP_X	0.624	32.4	19.1