On Stereo Correspondence Estimation: A Spiral Search Algorithm

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***Abstract*—This paper introduces a searching algorithm called "spiral searching" for computing stereo correspondence or disparity of the stereo images. The method is based on computation of the minimum window cost among the contributions of the windows bounded in the range from minimum depth of spiral to maximum depth of spiral. This algorithm can estimate stereo correspondence of a pair of images concurrently two dimensionally and it avoids false matching causes to increase the accuracy and requires minimum executing time than the traditional one dimensional searching strategies. This method first calculates two window costs - one in positive *x*-direction and another in negative *y*-direction using the same distance from the origin. Minimum of the two window costs and coordinate distances are considered for second calculation. Secondly, following the same way another two window costs are calculated - one in negative *x*-direction and another in positive *y*-direction using the same distance from the origin. Minimum of the two window costs and coordinate distances are compared to the previous two window costs. This process is bounded from minimum depth of spiral to maximum depth of spiral. Experimental result demonstrates that the visual quality of the output image is very close to ground truth image.**

Keywords: Stereo correspondence, window cost, spiral searching, disparity, sum of absolute differences, normalized correlation.

I. INTRODUCTION

The difference in the coordinates of left image and right image of the corresponding pixels is known as stereo correspondence or disparity, which is inversely proportional to the distance of the object from the camera. Stereo correspondence is a common tool in computer or robot vision, essential for determining three-dimensional depth information of object using a pair of left and right images from a stereo camera system. For of a pixel in the left image, its correspondence has to be searched in the right image based on epipolar line and maximum disparity. Stereo correspondence is conventionally determined by matching windows of pixels using Sum of Square Differences (SSD), Sum of Absolute Differences (SAD), or normalized correlation techniques.

Window-based stereo correspondence estimation technique is widely used due to its efficiency and ease of implementation. However, there is a well-known problem in the selection of an appropriate size and shape of window [1-2]. If the window is small and does not cover enough intensity variation, it gives erroneous result due to low signal to noise ratio. If, on the other hand, the window is large, it includes a region where the disparity varies or discontinuity of disparity happens, then the result becomes erroneous due to different projective distortions in the left and right images. Pixels that are close to a disparity discontinuity require windows of different shapes to avoid crossing the discontinuity. Therefore, different pixels in an image require windows of different shapes and sizes.

To overcome this problem, many researchers proposed adaptive window techniques using windows of different shapes and sizes [3-7]. In adaptive window technique, it requires comparing the window costs for different window sizes and shapes, so the computation time is relatively higher than that of fixed window technique. For example, in the references 6 and 7 the authors used a direct search over several window shapes to find the one that gives the best window cost. Beside gray scale stereo images, the use of color stereo images brings a substantial gain in accuracy with the expense of computation time [8]. Some applications, like autonomous vehicle and robot navigation, virtual reality and stereo image coding in 3D television, require a very fast estimation of dense stereo correspondence [9-10]. The Virtual Masking System [9] is also employed in this paper. The Virtual Masking System technique improves the computation efficiency by excluding unlikely correspondences; this Virtual Masking System is based on the stereo matching constraint that states the corresponding pixels should be close in color or intensity [10]. In our earlier methods, we used two-stage Approximation Algorithm, Arbitrary Window Pixel, Diagonal Mask Searching [11-12] and survived the minimum value among three searches to overcome the window-based problems. The proposed method is able to avoid false matching in the right image pixels causes to increase the visual quality of the estimated stereo correspondence and search performed concurrently two –dimensionally to the right image causes to reduce the computational time, ensures the better quality of experimental disparity image as shown in Figure 2 to Figure 7.

II. SPIRAL SEARCH TECHNIQUE

A new stereo imaging search technique has been introduced in this section, where spiral search range is shown in Figure 1 in which the search areas are ($-C_{xmin}$, $-C_{ymin}$) to

($+C_{xmax}$, $+C_{ymax}$) instead of using $-d_{max}$ to $+d_{max}$ that is used as a traditional search range. Accordingly, the spiral search is performed by two ways. First one is from the first and third quadrants of the right image starting from the minimum depth to the origin point. Second one is of fourth and second quadrants starting from origin to the maximum depth of search range of right image. Each pixel of left image has been concurrently searched in the two spiral regions according to the above mentioned search technique. This is one kind of two-dimensional simultaneous search technique avoiding the repetition of redundant pixels and false matching.

In the spiral search any pixel of left image has been first compared and calculated the window cost along with the positive *x*-direction of right image as shown in Figure 1. Secondly, this pixel has also been compared for calculating the contributions made in the window cost along with the negative *y*-direction of right image followed by one co-ordinate distance gap. In the two cases, two different window costs are estimated d_1 and d_2, respectively. Similarly, in the second way, for that pixel of the left image another search has been established starting from the origin to the maximum range along with the negative *x* direction and positive *y* direction followed by one co-ordinate distance gap. Accordingly, two different window costs are estimated d_1 and d_2, respectively. Using standard minimum function minimum window costs $\boldsymbol{W_C}(x, y, d_i)$ are stored in the array d_i. In search conclusion, the final disparity *d* is estimated from the set of elements $\boldsymbol{W_C}(x, y, d_i)$.

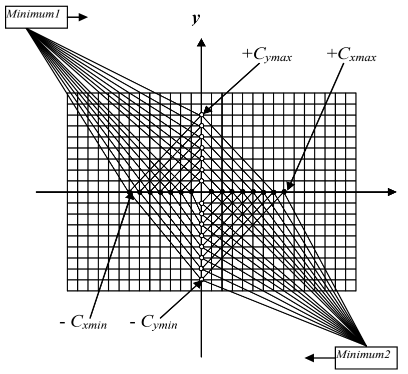

Figure 1. Illustration of spiral search method.

III. SPIRAL SEARCH ALGORITHM

1. Start.
2. Repeat step 2 to 5 for each pixel (x,y)
3. Repeat step for $C_{id} = -C_{min}$ to $+C_{max}$ *do*
   calculate $\boldsymbol{Wc}((x+c_{id}*2),y,d_1)$
   calculate $\boldsymbol{Wc}(x,(y+c_{id}*(-2)+1),d_2)$
   $\boldsymbol{Wc}(x,y,d_i) = min(d_1,d_2)$
4. [End of the step 3]
5. Find best $\boldsymbol{Wc}(x,y,d) \in \boldsymbol{Wc}(x,y,d_i)$
6. [End of the step 2]
7. Disparity of $(x,y) = d$
8. Stop

IV. EXPERIMENTAL RESULTS

This section provides experimental results on standard stereo images (tsukuba Head). The input images are provided by the computer vision and image Media Laboratory University of Tsukuba, Japan. Figure 8 shows standard ground truth image (Reference image). Figure 2 – 7 show the disparity images calculated from left and right image applying spiral search algorithm.

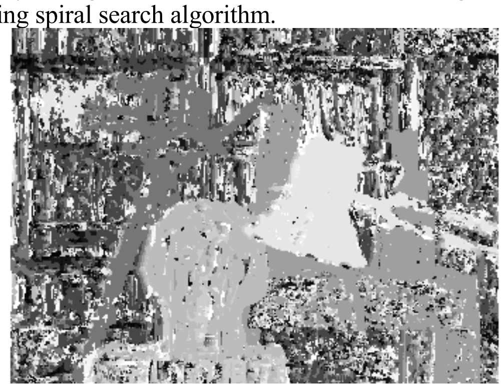

Figure 2. Stereo Correspondence window size 3×3.

Figure 3. Stereo Correspondence window size 5×5.

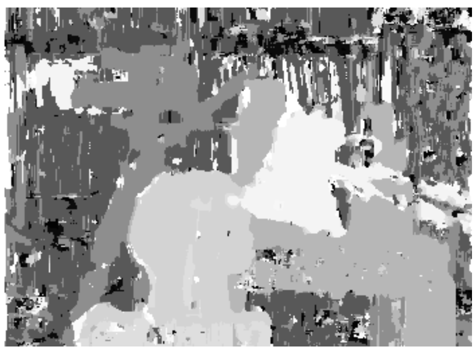

Figure 4. Stereo Correspondence window size 7×7.

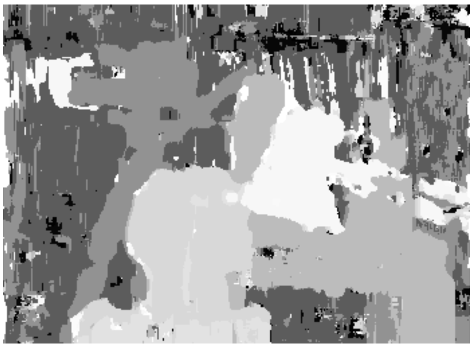

Figure 5. Stereo Correspondence window size 9×9.

Figure 6. Stereo Correspondence window size 11×11.

Figure 7. Stereo Correspondence window size 15×15.

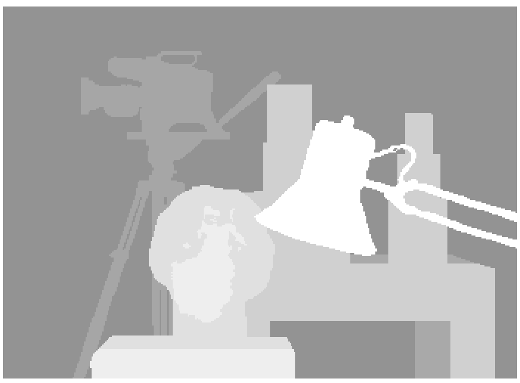

Figure 8. Standard ground truth image.

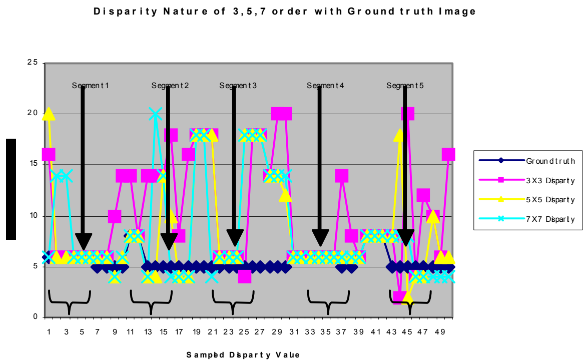

Figure 9. Disparity variations with different window sizes.

Among the experimental stereo correspondences Figure 2, Figure 3 and Figure 4, the best stereo correspondence which is close to meet the ground truth image is Figure 4, corresponding to the window size 7×7. Figure 9 shows the stereo correspondence or disparity nature that is drawn on the basis of disparity intensity of the certain positions of the output image. The disparity nature is classified to different segments on the basis of similarity and dissimilarity regions of ground truth image and output images. From segment 1, all disparities are coincided with the ground truth image which means 100% similarity between the ground truth image and the output image occurs for the window size 3×3, 5×5, 7×7. In segment 2, minimum variations occur only for window size 5×5. So the best similarity produces due to the window size 5×5 for this segment only. Segment 3 results approximately like segment 1. Segment 4 performs the results like segment 1. In segment 5 the maximum variation occurs for only 3×3 window size and minimum variation occurs for due to 7×7 window size. Experimental results revealed that more sharpness and brightness for the output image occurs due to 7×7 window size and worst sharpness and brightness due to 3×3 window size.

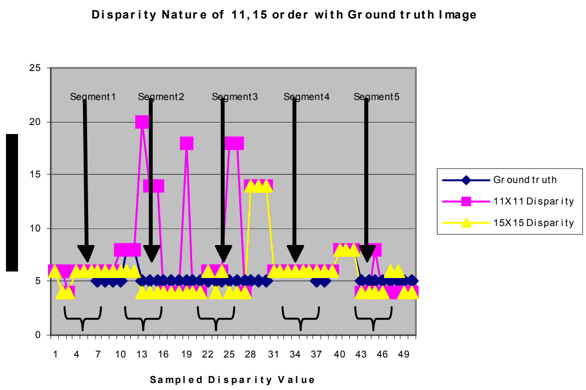

Figure 10. Disparity Variation with Different window size.

Figure 10 is drawn based on the disparity values of Figure 6 and Figure 7 in which 11×11 and 15×15 window sizes are used respectively. The output image of Figure 6 and Figure 7 are approximately same but some noise have been discarded from the output image of Figure 7 because noise is reduced two dimensionally due to avoid false matching associated with the wide range of window size 15×15. In segment 1 all disparity lines are coincided with the ground truth image which means 100% similarity between the ground truth image and the output image occurs for the window sizes 11×11 and 15×15. In segment 2 minimum variations occur only for window size 15×15 of output image. So the best similarity occurs due to the window size 15×15 for this segment only. Rest of the segments result approximately like segment 1.

V. CONLUSION

This paper presents a fast window based matching algorithm for disparity computation, which can explicitly construct rectangular windows. Window size and shape selection is a difficult problem in area based stereo. We have proposed an algorithm, which chooses an appropriate window shape by optimizing over a large class of "compact" windows. Most of the noises have been discarded from output image of Figure 7 for the window size 15×15.The spiral search algorithm is cable of finding the appropriate window size for stereo correspondences estimation. The proposed algorithm can explore the best window size of a stereo images for a particular segment, are explained in Section IV.

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