Disparity Estimation by Reverse Fuzzyfication

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***Abstract*—This paper presents an algorithm using fuzzy logic for computing disparity or stereo correspondence of the image sequences. For better achievements, reverse fuzzyfication method has been employed for disparity estimation. The algorithm stands on verdict the preeminent counterpart for every window's pixel in the left image with the consequent right image of all the pixels and setting the fuzzy value for measuring the stereo correspondence. In this method 3×3 window size has been used and every pixel has been considered for estimating stereo correspondence. Discrete membership function is used based on the basis of the pixel value difference between left and right images for fuzzyfication. Experimental results demonstrate that the proposed algorithm's computational cost is much less than the fixed and adaptive window based methods, and it requires less memory space too. The proposed method has been applied to standard stereo images and the results imply that we can easily reduce the computational time of about 50% with no appreciable degradation of accuracy.**

Keywords-fuzzy logic, stereo matching, stereo correspondence, window cost.

I. INTRODUCTION

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 stereo correspondence. Stereo correspondence is conventionally determined by matching windows of pixels by 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 results due to low signal to noise ratio. If, on the other hand, the window is large, it includes a region where the stereo correspondence varies or discontinuity of stereo correspondence happens, then the result becomes erroneous due to different projective distortions in the left and right images. Pixels that are close to a stereo correspondence 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 these problems, 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 the fixed window based technique. For example, in the references [8] and [9] the authors used a direct search over several window shapes to find the one that gives the best window cost. Apart from the gray scale stereo images, the use of color stereo images brings a substantial gain in accuracy with the expense of computation time. Some applications, like autonomous vehicle and robot navigation, virtual reality and stereo image coding in 3D-TV, require a very fast estimation of dense stereo correspondence.

Proposed method based on fuzzy systems is an alternative to traditional notions of set membership and logic is based on the of corresponding pixels and finding the minimum value among three searches to overcome the window-based problems. During processing, stereo correspondence image pixel was fuzzyfing using discrete membership function leads to reduce the number of comparisons as well as computational time. Hence, based on this technique, the proposed method takes near about real time to compute the stereo correspondence and thus ensures the better quality of stereo correspondence image from a pair of image sequences.

II. STEREO CORRESPONDENCE ESTIMATION

In stereo scheme, two images of the same scene are taken from slightly different viewpoints using two cameras, placed in the same lateral plane. For most of the pixels in the left image there is a corresponding pixel in the right image in the same horizontal line. The difference in the coordinates of the corresponding pixels is known as stereo correspondence, which is inversely proportional to the distance of the object from the camera, given by the equation:

$$d = x_L - x_R = \frac{Bf}{z} \tag{1}$$

Where d is the stereo correspondence, f is focal length of the camera, z is the distance of the object point from the camera (the depth), and B is the baseline distance between two cameras, respectively.

Stereo correspondence, which is an important factor for determining three-dimensional depth information of objects, is conventionally determined based on matching windows of pixels by using SSD, SAD or normalized correlation techniques [2]. To determine the correspondence of a pixel in the left image using SSD, SAD or normalized correlation techniques the window costs (i.e., SSD or SAD or correlation values) are computed for all candidate pixels in the right image within the search range. The pixel in the right image that gives the best window cost is the corresponding pixel of the left image. A constraint in the stereo matching is that the corresponding pixels should be close in color or intensity. Based on this constraint a fast fuzzy technique is employed in this work, where it is not necessary to compute the window costs of all candidate pixels in the right image within the search range. To determine the correspondence of a pixel in the left image we just compute the window cost for pixels in the right image whose intensities are different within a class interval value to form the fuzzy membership (in reverse order). To overcome those problems which are mentioned in the introduction section, we proposed a stereo correspondence computation technique for window based -using reverse fuzzy technique based on local variations of intensity and stereo correspondence. The estimation of window cost is given by the following equations:

$$W_c^{SAD}(x,y,d)=\sum_{i=1}^{W_x}\sum_{j=1}^{W_y}\left|I_L(x+i,y+j)-I_R(x+i+d,y+j)\right| \tag{2}$$

$$W_c^{SSD}(x,y,d)=\sum_{i=1}^{W_x}\sum_{j=1}^{W_y}\left\{I_L(x+i,y+j)-I_R(x+i+d,y+j)\right\}^2 \tag{3}$$

where $I_L(x,y)$ and $I_R(x,y)$ are the intensities of the pixel at a position (x,y) obtained at the left and right images, respectively, $W_c^{SAD}(x,y,d)$ and $W_c^{SSD}(x,y,d)$ are the window costs of a pixel at position (x,y) in the left image due to SAD and SSD calculations, respectively, with stereo correspondence d, W_x and W_y are the window width and height, respectively. In this research, window cost calculation is performed based on the SAD method

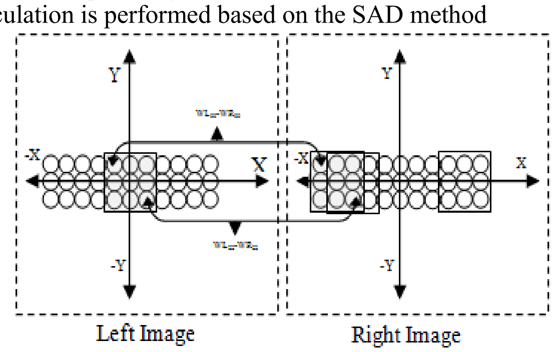

Figure 1. Disparity in a stereo pair of images.

Figure 1 shows the expansion of right image co-ordinate that interprets the computational technique of stereo correspondence of (x,y) co-ordinate of left image.

III. REVERSE FUZZYIFICATION FOR DISPARITY ESTIMATION

A new concept has been introduced here known as reverse fuzzyfication for disparity estimation, as shown in Figure 1. In this technique membership value Π is calculated on the basis of gray level difference of left image and right image. If the gray level difference more than 50, fuzzy membership value is set as *worst matching* assigned 1 membership value, on the other hand if the difference is 0 fuzzy membership value is set as *best matching* assigned the 0 membership value. This technique is shown in table I. For disparity estimation we use a fuzzy searching range $-f_{\max}$ to $+f_{\max}$ and a window cost W_c calculated for each fuzzy value f. Window size 3×3 is used for the calculation of window cost and for every window pixel of fuzzy difference of vector is estimated according to the class interval of five which is shown in Table II. Graphical interpretation of reverse fuzzy membership function is illustrated in Figure 2.

TABLE I. REVERSE FUZZYIFICATION MATCHING

Best Matching	Good Matching	Average Matching	Worse Matching	Worst matching
0.0	0.3	0.5	0.7	1.0

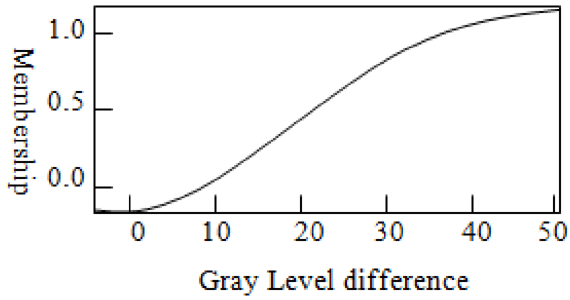

Figure 2. Graphical representation of membership function.

TABLE II. DISCRETE REPRESENTATION MEMBERSHIP FUNCTION:

Left window pixel	WL_{00}	WL_{01}	WL_{02}	WL_{10}	WL_{11}	WL_{12}	WL_{20}	WL_{21}	WL_{22}
Right window pixel	WR_{00}	WR_{01}	WR_{02}	WR_{10}	WR_{11}	WR_{12}	WR_{20}	WR_{21}	WR_{22}
Membership values	0	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1
Vector Difference(d)	Π (d=0)	Π (d>5)	Π (d>10)	Π (d>15)	Π (d>20)	Π (d>25)	Π (d>30)	Π (d>40)	Π (d>50)

Figure 3 shows the fuzzy guided search range from f_{-max} to f_{+max} of right image.

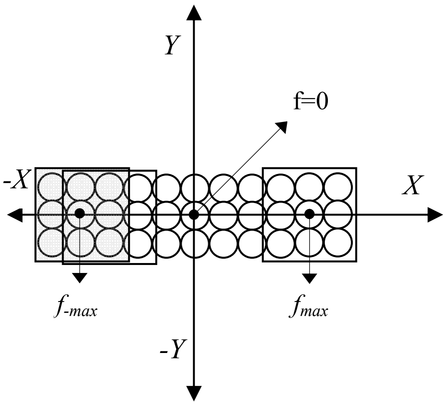

Figure 3. Graphical representation of searching range.

IV. DIAGONAL SEARCH ALGORITHM

1. Repeat step 2 to 5 For each window center pixel (x, y)
2. Repeat step 3 and 4 for each window value (j) do
3. Repeat step for $f = -f_{\max}$ to $+f_{\max}$ do
   (a) Calculate membership value Π (wl_j-wr_j)
   (b) Calculate $w_c(x, y, f + j)$ by adding all Π
   [End of the step 3]
4. Find best $w_c(x, y, f_i) \in w_c(x, y, f + j)$
   [End of the step 2]
5. Stereo correspondence of (x, y) is minimum distance of $w_c(x, y, f_i)$
   [End of the step 1]

V. EXPERIMENTAL RESULTS

The effectiveness of the algorithm has been justified in simple and complex backgrounds for different types of images of different resolutions. The algorithm is capable of finding the disparity map in images with different backgrounds and lighting conditions. In order to demonstrate the accuracy and speed of this algorithm, we present the processing results from standard and real image pairs, including ones with ground-truth values for quantitative comparison with other methods. Experiments are carried out on a Intel Core 2 Duo 2.4 GHz PC with 1 GB RAM. The algorithm has been implemented using Visual C++. The dense disparity map is obtained using some standard stereo images (Tsukuba Head) whose dense ground truth is known. The images are provided by the Computer Vision and Image Media Laboratory, University of Tsukuba, Japan. Figure 4 and Figure 5 show the Tskuba Head images. Figure 6 illustrates the stereo correspondence image calculated from left and right image applying reverse fuzzyfication method. Figure 7 illustrates the computation of disparity by city block distance, in which central fuzzy search point is f_0. Minimum fuzzy window cost is 0.2 and its corresponding fuzzy range is f_2. So the coordinate distance from f_0 to f_2 is 2.Thus disparity is set to 2.

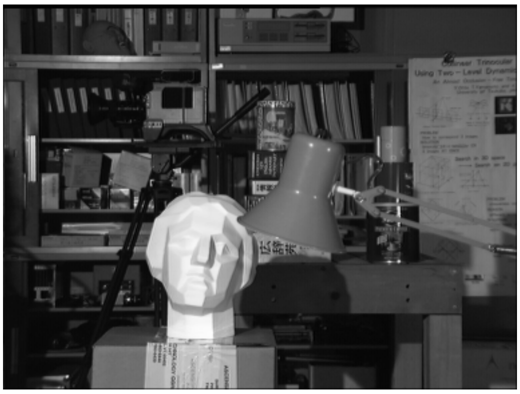

Figure 4. Left image 384×288.

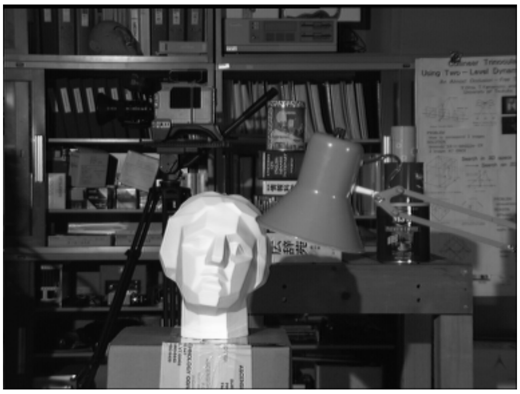

Figure 5. Right image 384×288.

Figure 6. Extrapolated image 348×252.

Fuzzy range	f_{-4}	f_{-3}	f_{-2}	f_{-1}	f_0	f_1	f_2	f_3	f_4
Window costs	9	3	4	3.1	8	4	0.2	1.5	4

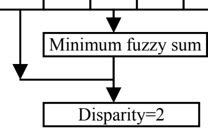

Figure 7. City block distance for disparity estimation.

Table III shows the summary of comparison between Window – based method (traditional) and reverse fuzzy system (proposed method). Table III shows that the reverse fuzzy system of a 3×3 window size is applicable for both methods simultaneously which indicates that the proposed method is a reduction of 50% of computational time. The size of the left and right image is (width×height) = (384×288) pixels, stereo correspondence image size is (width×height) = (116×84) pixels and extrapolated image size is (width×height) = (348×252) pixels.

TABLE III. COMPUTATIONAL TIME REDUCTION (%) WITH WINDOW BASED METHOD.

Method	**Window size**	**Computational time (in second)**	**Computational Time reduction (%)**
Window based method	3 ×3	0.93	**50 %**
Reverse Fuzzyfication Method	3 × 3	0.46	

VI. CONCLUSION

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. The performance of this algorithm has been justified over the standard images. Experimental results confirm that our method can easily reduce the computation time of about **50%** with no appreciable degradation of accuracy. We believe that the reverse fuzzy searching method will be useful for many applications where a very fast estimation of dense disparities is essential. For further improvement, the algorithm may be developed with more features for improvement of the smoothness of the disparity image. Our next approach is to use the disparity estimation technique for 3D scene reconstruction for robot navigation and intelligent vehicle navigation.

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