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Normalized Cross Correlation for Stereo Matching Under Varying Illumination

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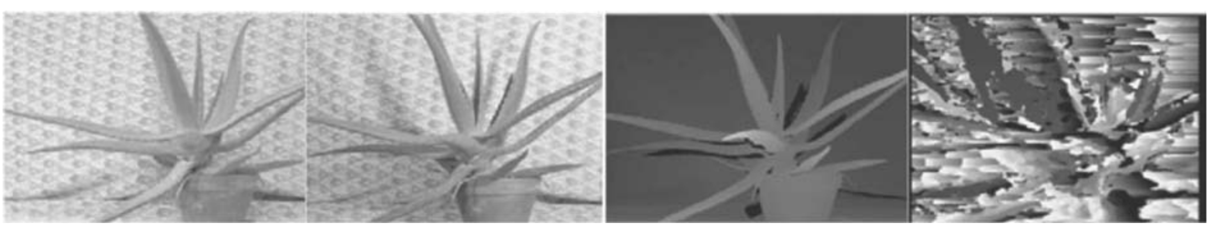
Abstract : One of the difficulties in obtaining a dense and accurate disparity map through stereo matching is the presence of radiometric variation in the two images used in this process.It is commonly assumed that in stereo matching, the corresponding pixels have similar pixel values. But the presence of this variation causes the regular methods to produce erroneous results. In this paper, we use the concept of normalized cross correlation for the matching purpose which provides a much better result when compared to intensity based methods like sum of absolute differences and sum of squared differences.

Keywords : Stereo matching, disparity map, normalized cross correlation.

1. INTRODUCTION

The main aim of stereo matching is to try to analyze images obtained from a stereo camera. We can acquire the depth of the various objects in the scene with the help of these images. One of the areas of active research is to identify appropriate corresponding points in the image pairs given. These algorithms can be classified into global and local algorithms [1]. Global algorithms are efficient but computationally expensive. The local algorithms are comparatively less efficient but the computational expense is considerably low. Hence, local algorithms are preferred for real-time applications. These methods generally use a window of fixed size and shape[2] [4].



Left ImageRight Image Ground Truth Disparity of SAD

Fig. 1. Output disparity of SAD stereo algorithm for radiometrically different image [3].

One of the main purpose of stereo vision-based matching algorithms is the estimation of depth.The result of a stereo matching process is a disparity map. The actual depth of the objects in the scene can be directly acquired from this map. Hence it is very important for a stereo algorithm to produce accurate disparity. In a real environment scenario, there are a few challenges for stereo algorithms.Some of them are radiometric variations such as change in illumination and exposure conditions, object occlusion, shadow, etc. This hampers the accuracy of the disparity

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estimation. Figure 1 shows an example, where the commonly used stereo matching algorithm (SAD) produces a poor disparity map, when subjected to radiometric variation [3].

2. NORMALISED CROSS CORRELATION

In order to obtain dense depth maps, generally correlation based matching is used and it calculates the disparity at each pixel within a neighborhood. A square window, around the pixel of interest is taken. The window size can vary depending upon the range of disparity and the level of accuracy needed. This window is taken around the reference image and a search is performed on the target image to find a homologous pixel within a similar window along the corresponding scan line. The main aim is to find the corresponding (correlated) pixel within a certain disparity range *d*[0,….,dmax] , such that, the particular pixel minimizes the associated error and maximizes the similarity.

In the matching process, we compute the similarity measure for each disparity value. Once the measures are found, the next step would be aggregation. These steps have a tendency to power consuming processes. Hence, we have to considerthe speed-performance advantages in optimizing the matching algorithm.The process of image matching could be performed by taking either left image as the reference (left-to-right matching) or right image as the reference (right-to-left matching).

One of the simplest similarity measure, which is used in stereo matching, is the sum of Absolute Differences (SAD. This method consists of calculating the similarity by subtracting the respective pixels within a square neighborhood between the reference image I1 and the target image I2.The next step would be to find the aggregate of the absolute differences and optimization is performed using the winner-take-all (WTA) strategy. Since it is a difference measure, if the left and right images exactly match, the result will be zero.

In Sum of Squared Differences (SSD), as the name suggests, the differences of each pixel within a window are squared and aggregated. The next step is to perform a winner takes all based optimization.This method has a higher computation when compared to SAD algorithm as it involves many multiplication operations.

NCC is a method for matching two windows around a pixel of interest. The normalization within the window compensates differences in gain and bias. Statistically speaking, when handling Gaussian noise, NCC is the optimal method.

To find the correspondent pixels normalized cross correlation is calculated between the intensity patterns of the pixel in the left image and intensity patterns of all possible candidates in the right image. Let p_l be the pixel intensity signal representing the pixel in the left image, p_r the pixel intensity signal of the candidate pixel in the right image. The normalized cross correlation is calculated as shown in the equation below[6]

$$ncc = \frac{\sum i(p_l(i) - \text{mean}(p_l)) * (p_r(i) - \text{mean}(p_r))}{\sum i(p_l(i) - \text{mean}(p_l))^2 * \sum i(p_r(i) - \text{mean}(p_r))^2}$$

3. METHEDOLOGY

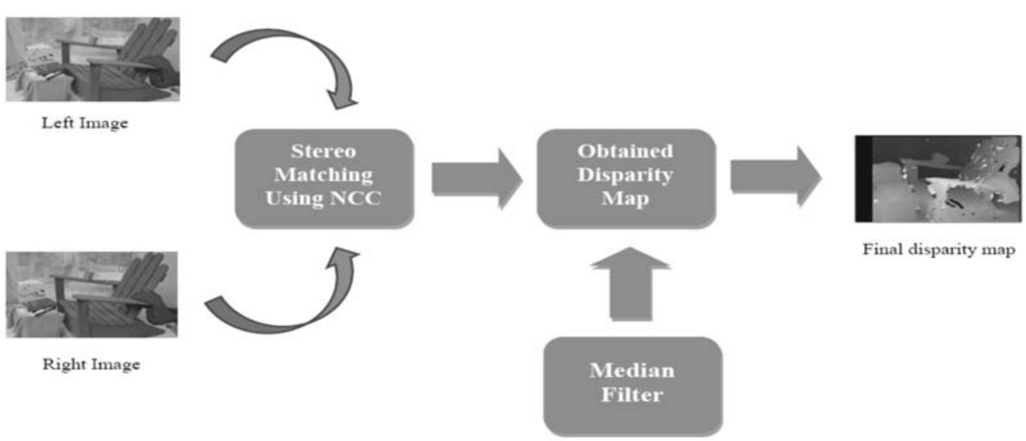

Fig. 2. Methodology used in this paper.

Figure 2 explains the methodology used for this research. The left and the right images, taken from the dataset, are initially matched using the normalized cross correlation function mentioned previously. The disparity map obtained through this process needs to be smoothened to reduce noise induced into the disparity map during the matching process. For this purpose, a 3X3 median filter is applied to the mentioned disparity map. The disparity map obtained after the smoothening process is taken as the final result and is uploaded to the Middlebury website for evaluation.

4. RESULTS AND CONCLUSION

Data set from the Middlebury Stereo Vision Page was used as it is a standard benchmark for stereo evaluation. Figure 3 shows some of the images of the mentioned dataset. As stated earlier, the SSD, SAD and the NCC algorithms are being compared and the result of applying these algorithms are shown in figure 4.

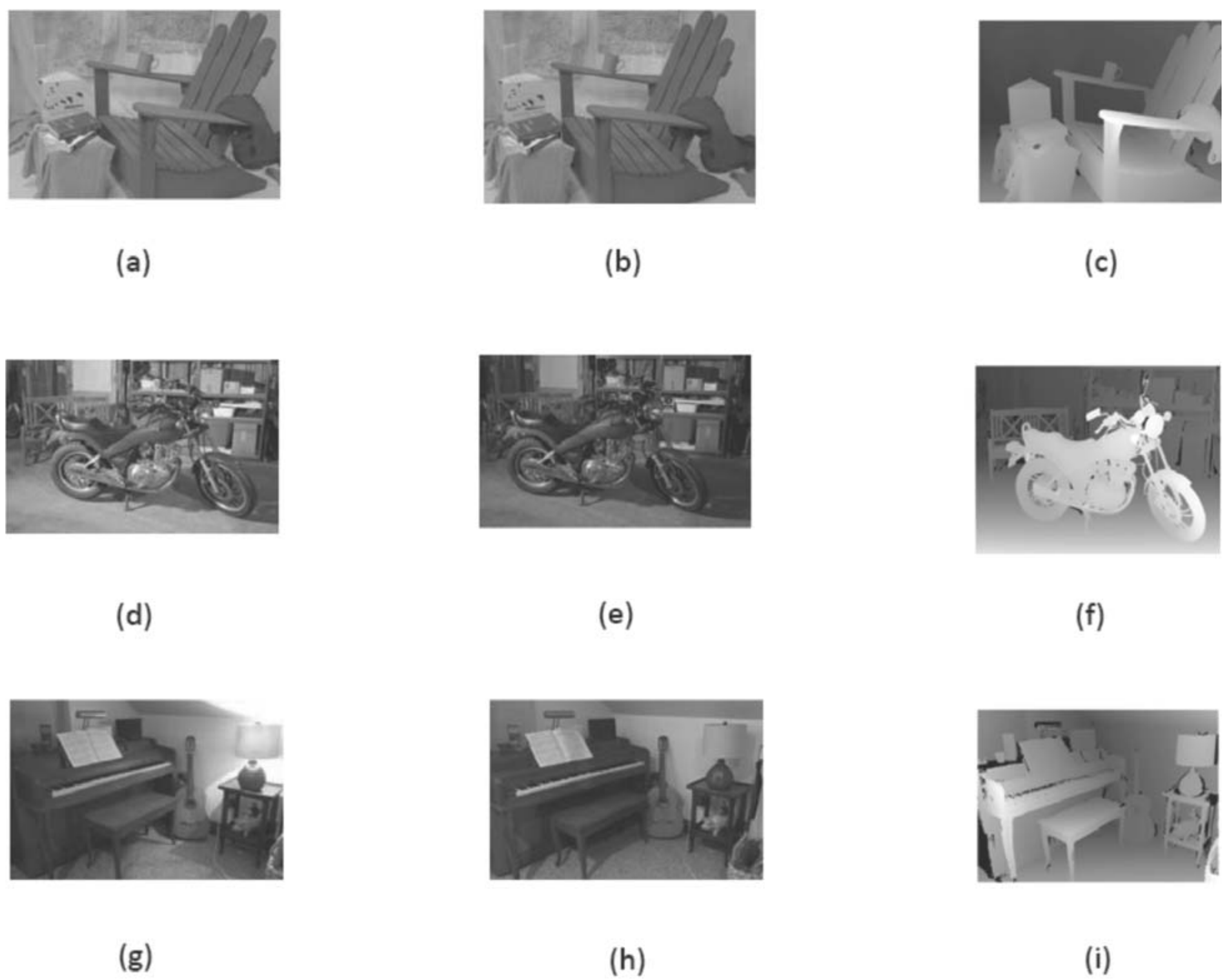

Fig. 3. Some of the images in the Middlebury Stereo Vision dataset (*a, d, g* are the left images and *b, e, h* are the right images) along with the respective ground truths(*c, f, i*) [5].

The results were uploaded to the Middlebury website for evaluation. The average error produced by the algorithm was 31.2 and it held a rank of 32 among the recently published algorithms in this area. Based on these results, we can safely say that NCC is a viable option for stereo matching in conditions of varying exposure. When it comes to extreme variations in illumination, the simple NCC might not provide us with the best results, but the algorithm can be further modified to provide a robust solution to the problem of varying illumination.

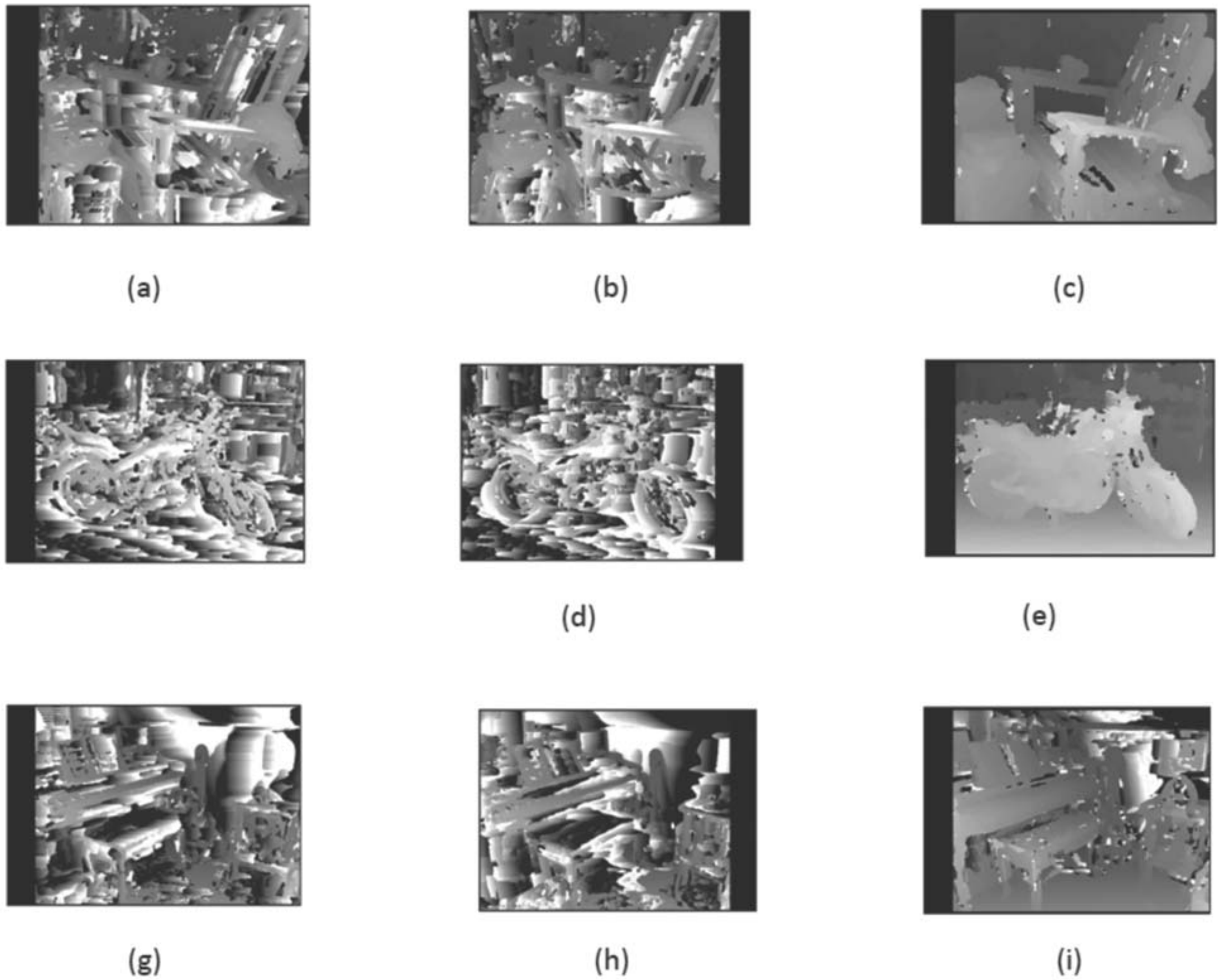

Fig. 4. Result of SAD (*a, d, g*), SSD (*b, e, h*) and NCC (*c, f, i*) algorithms respectively for the image sets mentioned above.

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