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Color Stereo Vision Using Hierarchical Block Matching and Active Color Illumination

Abstract

Stereo is a well-known technique for obtaining depth information from digital images. Nevertheless, this technique still suffers from a lack in accuracy and/or long computation time needed to match stereo images. A new hierarchical algorithm using an image pyramid for obtaining dense depth maps from color stereo images is presented. We show that matching results of high quality are obtained when using the new hierarchical chromatic Block Matching algorithm. Most stereo matching algorithms can not compute correct dense maps in homogenous image regions. This paper shows that using an active color illumination will considerably improve the quality of the matching results. We present results for synthetic and for real images.

Stereo Analysis using Block Matching

The main idea of Block Matching is a similarity check between two equal sized blocks (n x m) in the left and right image (area-based stereo). The mean square error MSE between the pixel values inside the respective blocks defines a measure for the similarity of two blocks with n=m=2k+1 as

$$MSE_{color}(x,y,\Delta) = \frac{1}{n \cdot m} \sum_{i=-k}^{k} \sum_{j=-k}^{k} \left(\left| R_R(x+i,y+j) - R_L(x+i+\Delta,y+j) \right|^2 + \left| G_R(x+i,y+j) - G_L(x+i+\Delta,y+j) \right|^2 + \left| B_R(x+i,y+j) - B_L(x+i+\Delta,y+j) \right|^2 \right)$$

The block is shifted pixel by pixel inside the search area. Using standard stereo geometry the epipolar lines match the image line. The disparity D of two blocks in both images is defined by the horizontal distance that shows the minimum MSE

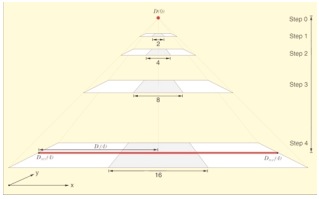
$$D = \min_{|\Delta| \le d_{max}} \{ MSE_{color}(x,y,\Delta) \}$$

The search area is limited in the horizontal direction by a predefined maximum disparity. Block disparities are median filtered to avoid outliers. A dense disparity map is generated using a pixel selection technique to every pixel in the image.

Left color stereo image ANDREAS and the depth map obtained when applying standard Block Matching to the images.

Hierarchical Block Matching Using Image Pyramids

We enhanced the chromatic Block Matching algorithm by using a quad pyramid. The disparities $D(s+1)$ at level $(s+1)$ can be derived from the disparities $D(s)$ of the preceding level (s) by applying a modified block matching algorithm to the image of level $(s+1)$.



Definition of the search space with a tolerance factor D_T = 3.0.

The search space for the disparity of each block at level $(s+1)$ is derived from the disparity of the corresponding block at level (s) by a tolerance factor D_T. This parameter defines the width D_Δ of the reduced search space $[D_{MIN}, D_{MAX}]$ and controls the smoothness of the disparity map

$$D_\Delta(s) = 2^{(s-1)} \cdot D_T$$

$$D_{MIN}(s) = \begin{cases} D(0) - D_\Delta(s) & \text{for } s = 1 \\ D_{MIN}(s-1) - D_\Delta(s-1) & \text{for } s > 1 \end{cases}$$

$$D_{MAX}(s) = \begin{cases} D(0) + D_\Delta(s) & \text{for } s = 1 \\ D_{MAX}(s-1) + D_\Delta(s-1) & \text{for } s > 1 \end{cases}$$

When choosing a small value for the tolerance factor D_T, the difference between the final disparities and the average disparity found at level 0 will be very small. This is equivalent to a small variation of disparities over the whole image. A larger tolerance factor will cause a bigger search space and the influence of the computed disparities in the preceding levels will decline.

Comparing the standard Block Matching with the hierarchical Block Matching, the enhanced algorithm is more robust and shows better results. Furthermore, the hierarchical approach can be implemented very efficiently in parallel to achieve high speed execution.

Enhanced depth map using hierarchical Block Matching and the 3-D reconstruction with texture mapping.

Active Color Illumination for Enhancing Stereo Matching

Most stereo matching algorithms can not compute correct dense depth maps for homogenous image regions. This is due to the ambiguity of the image values and can be eliminated by adding a synthetic texture to the scene.

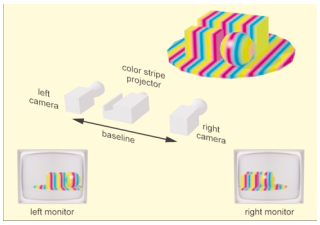
We projected a rainbow like color spectrum onto the scene. Every row of length n in the color spectrum S_{RGB} was generated using the equations

$$S_R = \sin\left(\frac{i}{n} \cdot \pi\right) \cdot \left(\frac{G_{MAX}}{2} - 1\right) + \frac{G_{MAX}}{2}$$

$$S_G = \sin\left(\left(\frac{2}{3} + \frac{i}{n}\right) \cdot \pi\right) \cdot \left(\frac{G_{MAX}}{2} - 1\right) + \frac{G_{MAX}}{2}, \quad i = \{0, \ldots, n\}$$

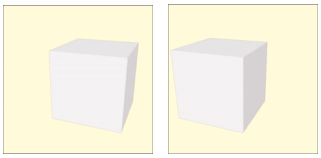
$$S_B = \sin\left(\left(\frac{4}{3} + \frac{i}{n}\right) \cdot \pi\right) \cdot \left(\frac{G_{MAX}}{2} - 1\right) + \frac{G_{MAX}}{2}$$

where i denotes the column position in the spectrum image and G_{MAX} denotes the maximum intensity value in every color channel.

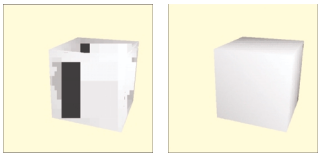


Principle of the stereo system using active color illumination.

Experimental Results with Synthetic Images



The synthetic gray value stereo image pair CUBE.

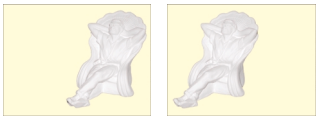


Disparity map computed for CUBE and result obtained with the color spectrum.

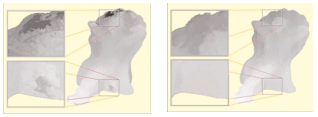
Difference (in pixel)	Intensity images (%)	Color images (%)
0	7.9	62.2
1	12.2	25.8
≥2	79.8	12.0

Distribution of the matching errors (in percentage) for the gray value images and for the images superimposed with the color spectrum.

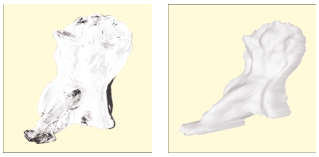
Experimental Results with Real Images



The real stereo image pair RELAXING JACK.



Computed depth maps obtained with (right) and without (left) active illumination.



Difference (scaled) between both depth maps and shaded representation of the reconstructed scene.

Summary

We should like to emphasize that active colored illumination always serves to improve stereo matching results. Therefore, we believe that more precise results can be efficiently obtained in dense stereo matching when combining hierarchical chromatic Block Matching with the active color illumination approach.