A Novel Horizontal Disparity Estimation Algorithm Using Stereoscopic Camera Rig

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***Abstract*— Image segmentation is always a challenging task in computer vision as well as in pattern recognition. Nowadays, this method has great importance in the field of stereo vision. The disparity information extracting from the binocular image pairs has essential relevance in the fields like Stereoscopic (3D) Imaging Systems, Virtual Reality and 3D Graphics. The term 'disparity' represents the horizontal shift between left camera image and right camera image. Till now, many methods are proposed to visualize or estimate the disparity.**

In this paper, we present a new technique to visualize the horizontal disparity between two stereo images based on image segmentation method. The process of comparing left camera image with right camera image is popularly known as 'Stereo-Matching'. This method is used in the field of stereo vision for many years and it has large contribution in generating depth and disparity maps. Correlation based stereo-matching are used most of the times to visualize the disparity. Although, for few stereo image pairs it is easy to estimate the horizontal disparity but in case of some other stereo images it becomes quite difficult to distinguish the disparity. Therefore, in order to visualize the horizontal disparity between any stereo image pairs in more robust way, a novel stereo-matching algorithm is proposed which is named as "Quadtree Segmentation of Pixels Disparity Estimation (QSPDE)".

***Index Terms*— Image Segmentation, Stereo-Matching, Correlation, Quadtree Segmentation of Pixels Disparity Estimation.**

I. INTRODUCTION

THIS paper is the continuation of the original format and contents with all the sections elaborated with more in-depth analysis and characteristics discussions [1]. There are more technical details comprising the facts and features of all existing methods and hence it reflects the difference between them and our current research.

Image segmentation is a vital step in image processing as well as in 3D reconstruction. It plays a crucial role in image analysis. In stereo vision, image segmentation is a challenging process of partitioning a stereo image pairs into multiple segments. The main purpose is to partition a digital image into smaller segments (set of pixels) which are much easier to analyze. Each of the pixels (smaller blocks or segments) in a region has some properties or characteristics such as color, intensity, or texture. Normally, based on these classifications, the two digital images or stereo image pairs are compared. Applications of image segmentation range from stereo vision, 3D reconstruction, filtering of noisy images, medical imaging, locating objects to problems of texture extraction, feature extraction and recognition [2].

In the field of stereoscopic imaging technology, stereo-matching methods are widely used in order to obtain depth and disparity maps of stereo image pairs. Most of the stereo-matching techniques are either area based or feature based. Almost in all the area based methods, the popular approach for visualizing the disparity is through correlation method while in feature based, the matching is performed either by edge detection or texture extraction methods. By the correlation method, any particular area or corresponding points are chosen and then it is compared with the area or points of other image. Usually, after viewing from different aspects, feature based stereo algorithm is considered as more pragmatic rather than area based [3]. But, this is only relevant on those stereo image pairs where horizontal disparity is easy to visualize. In case of some other stereo image pairs where visualization of disparity becomes little difficult, feature based algorithm is not sufficient to obtain the desire result.

In this paper, the main goal of the research is to easily visualize the horizontal disparity between any two stereo image pairs. So, area based stereo-matching technique is taken into account rather than the feature based. Hence, considering of all sequences as mentioned above, a new algorithm is proposed for disparity visualization which is eventually based on correlation method but not limited to choose any fixed size of particular area or points.

The foremost requisite step to obtain the disparity is to get the stereo image pairs. For this purpose, stereoscopic camera rig system which consists of two camcorder cameras placed on a horizontal rig base is used. In order to obtain clear stereoscopic images, only horizontal movement of the cameras is considered. As the rig base can only move in horizontal directions, therefore, the vertical shift between the two cameras is considered as zero. The base model of the stereoscopic camera rig system is shown in Fig. 1(a). Fig. 1(b) shows the top view of the camera rig which clearly describes about the horizontal movement of the two cameras when placed on

Manuscript received December 28, 2010; revised February 4, 2011; accepted February 9, 2011.

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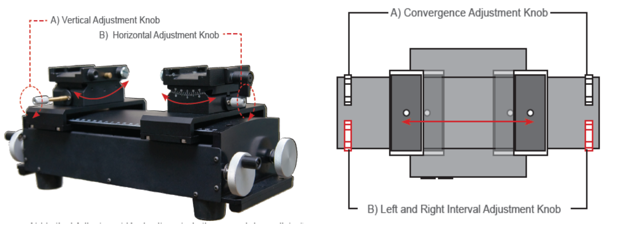
the rig model. The terms 'vergence' and 'focus' are also controlled depending on the movements of the two cameras. Movement of both cameras in opposite directions as shown in Fig. 1(b) increases the disparity and decreases the depth between the two images. On bringing the cameras close to each other decreases the disparity and develop more depth.

The rest of the paper is organized as follows: In section II, we review the related work. In section III, horizontal disparity visualization technique based on correlation method is described. In section IV, visualization of horizontal disparity using 'Gabor' and 'Canny' filters are discussed. In section V, our proposed method of estimating the disparity which is much more relevant as compared to the correlation method is discussed. In section VI, the experimental results are presented. In section VII, we conclude the stereo-matching technique of stereoscopic images.



(a) (b)

Fig. 1. (a) 3D camera rig base model on which two camcorder cameras are mounted, (b) top view of the rig system showing the horizontal movement of cameras.

II. RELATED WORKS

In this section, we review the related works for disparity estimation taken from stereoscopic camera rig system, disparity based on correlation method and different stereo-matching algorithms based on quad tree segmentation of stereo image pairs.

Xiaodong et al. [4] presents disparity estimation method combining phase based and energy based algorithm using 'Gabor' filter by fourier transform. A set of quadrature-pair 'Gabor' filters is used to estimate the disparity from the local phase correlation.

M. Ali et al. [5] propose the feature or texture extraction method by using canny edge detection based on computing the squared gradient magnitude. The main motive of using 'Canny' edge detection was to derive an 'optimal' operator for detecting the edges and finding their accurate localization. The accuracy of detecting the edges is found to be inversely proportional to their localization. The more accurate the detector is, the less accurate the localization.

K. C. Kwon et al. [6] proposed a binocular stereoscopic camera vergence control method for getting horizontal disparity information. The key-object in left and right images are extracted by labeling the centre area of image and then the disparity information is estimated.

J. E. Dudgeon et al. [7] presented the difference between the column positions of the corresponding left and right image points. A pair of stereo images is epipolar or raster scan aligned as the first step in location of image feature points. The image point in the right image which gives the maximum correlation value is chosen as the corresponding point for the associated point in the left image. The same procedure is repeated for all the points in the left image.

Y. K. Kim et al. [8] presented a new stereo matching algorithm using global and local color segmentation. In order to generate global segments, the image is divided into M*M blocks using quad-tree decomposition. The decomposition splits the block into smaller pieces. The maximum size of the block is set as M*M and minimum size N*N. Iteration process is performed for each blocks and sub-blocks.

D. R. Clewer et al. [9] describes the performance of stereo image compression using quad-tree disparity estimation against fixed block size disparity estimation. For quad-tree estimation a maximum of 16*16 and a minimum of 2*2 blocks are used. Finally, the resultant disparity map of fixed block size as well as disparity map of quad-tree segmentation of smaller blocks is obtained.

M. Gong et al. [10] presented a new framework depending on the quad-tree based genetic algorithm to solve many computer vision problems.

J. N. Ellinas et al. [11] proposed a new optimized technique of coding stereoscopic image sequence. The proposed technique is called as Enhanced Interpolated Motion and Disparity Estimation (EIMDE) in which a variable block size scheme has been employed for motion and disparity estimation. The block size is controlled by quad-tree decomposition of the processed frame.

III. VISUALIZATION OF HORIZONTAL DISPARITY BASED ON CORRELATION METHOD

Stereo-matching has been studied in the field of stereo vision for many years. This method brings great contribution for generating disparity and depth maps. One of the most popular approaches of stereo-matching technique for horizontal disparity visualization is through 'correlation' method. This method is widely used in the field of stereoscopic imaging systems. Based on the correlation method, epipolar lines or constraints are used for estimating the horizontal disparity. These lines play a crucial role in stereo-matching method. In case of parallel-axis stereoscopic camera, the parallel epipolar lines or constraints are always considered. It is the effect of these lines that disparity estimation in horizontal directions is more viable in comparison to the vertical directions [12]. Usually, by correlation technique a particular windowed region in left camera image and right camera image is taken instead of taking whole image [13]. The windowed region in right camera image is taken on an epipolar constraint or raster which are further sub-divided into smaller equal blocks or segments. Thereafter, the selected windowed region in left camera image is compared with the smaller windowed regions of right camera image and then the disparity between the two images is visualized. At this moment, one limitation arises that the size of the window in both the images must be enough large for adequate stereo-matching.

After in-depth analysis of all existing methods, it is observed that for some stereo images, correlation based stereo-matching is used for disparity visualization but in case if the horizontal shift between the two images is not clearly visible then it brings the limitation of using correlation method. Hence, to estimate the horizontal disparity between any stereo image pairs in more robust way, a method is proposed which is named as "Quadtree Segmentation of Pixels Disparity Estimation (QSPDE)".

This proposed method is basically based on the concept of correlation method of stereo-matching but not limited to choose any fixed particular window size of image and then compare with the same window size in other image. Also, in this method it is not required to take any epipolar line or constraint in right camera image for estimating the disparity between two stereo images.

IV. HORIZONTAL DISPARITY VISUALIZATION USING 'GABOR' AND 'CANNY' FILTERS

As it is seen earlier, the horizontal disparity between two images is estimated by area based correlation method in which epipolar lines or constraints is considered. The best matching correlation found is then used to estimate the disparity [14]. Now, feature based stereo-matching is conceptualized which further includes edge detection and texture extraction methods. Disparity is visualized when the filter is totally inside the stereo image pairs. For this purpose, 'Gabor' filter is regarded as a useful filter for horizontal disparity visualization [15]. Although, considering feature based stereo-matching method, 'Gabor' filter is found to be appropriate for texture extraction, representation and discrimination between two stereo pairs [16]. Also, 'Canny' edge detection is used which is basically proposed as a computational theory of optimal edge detection algorithm for better localization of the edges [17]. Texture extraction method using 'Gabor' filter involves following steps:

(1) The left camera color image and right camera color image is converted into grayscale.
(2) 'Gabor' filter is applied on both grayscale images.
(3) The horizontal disparity is visualized between two stereo image pairs.

Feature based correlation method using 'Canny' filter is used almost similar to steps of 'Gabor' filter. The major differences between both filters are:

(1) In case of 'Canny' filter, direct conversion of the color stereo image pairs into color edge detection without converting them into grayscale is possible [18].
(2) By the use of this filter, it is easy to visualize all the corresponding edges or points to estimate the clear disparity as compared to edge detection by using 'Gabor' filter.
(3) The use of 'Canny' filter also helps to reduce the computation time and effectiveness for estimating the disparity in comparison to the disparity visualization using 'Gabor' filter.

After considering all mentioned points above, the use of 'Gabor' and 'Canny' filters has got some limitations that they are useful for estimating the horizontal disparity for few stereo image pairs. In case of some other stereo images it becomes elusive job to estimate the disparity by using feature based correlation method including the use of both filters.

Therefore, in this paper, for better visualization of any stereo image pairs, a new method is proposed which is named as QSPDE. This method brings maximum clarity or distinctness of an idea of using area based correlation method in comparison to the feature based stereo-matching.

V. OUR PROPOSED METHOD: QUADTREE SEGMENTATION OF PIXELS DISPARITY ESTIMATION

Image segmentation is one of the crucial steps in image processing of stereo image pairs. It is basically a low-level image processing method which works on smaller segments or pixels. On the other hand, it is the process of assigning pixels of an image to regions which have common properties [19]. Most of the work on 3D segmentation has been done using feature based stereo-matching techniques. Nowadays, segment based stereo-matching methods is largely used to generate depth and disparity maps. Although, feature based stereo-matching using correlation methods is modified regularly to give superior performance yet it brings few limitations of clearly estimating the horizontal disparity for few stereo image pairs.

The goal of our research is to overcome the limitation of using correlation method by the use of epipolar raster or constraints. Therefore, QSPDE method is proposed. In this method, the main approach is to divide an image irrespective of any size into smaller segments or pixels.

Using the quadtree segmentation method as shown in Fig. 2, both left camera image and right camera image is divided into four equal segments. Each segment is further divided into four another smaller blocks or pixels. Now, it is free to choose any one pixel of the left camera image and compare it with the corresponding pixel of right camera image in order to estimate the disparity. This method is more useful to visualize the horizontal disparity of any corresponding segment or pixels and thus the limitation of using a fixed size window and comparing with the other image containing epipolar lines or constraints is removed.

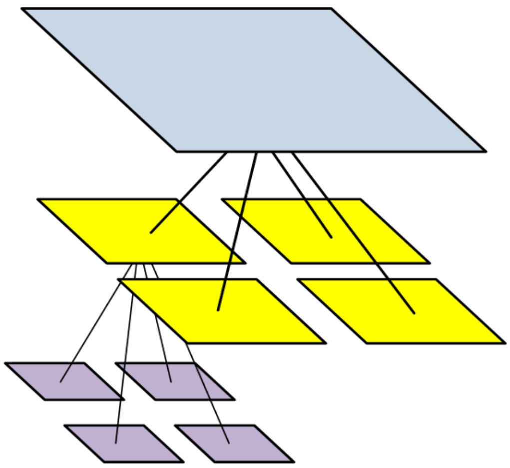


Fig. 2. Quadtree segmentation of an image.

In brief, if all the three methods (correlation, texture extraction and QSPDE) are compared to each other as well as the merits and demerits between them are analyzed as shown in Table I. It is observed that QSPDE method has got the merit to easily visualize the disparity for any stereo pairs whereas by correlation and texture extraction methods disparity can be easily visualized only for few stereo image pairs.

TABLE I
COMPARISON BETWEEN ALL THREE METHODS

Points	Correlation Method	Texture Extraction	QSPDE (Proposed Method)
Merits	Clear disparity for few stereo pairs	Disparity of particular area by edge detection	Easy disparity visualization for any stereo pairs
Demerits	Limitation is to choose a particular area or region	Difficulty in disparity estimation for any areas or regions	No demerits

The demerit of using correlation method is that a particular area must be chosen of irrespective size and then it is compared with the area of same size in right camera image. This method brings drawback to visualize the clear disparity if the size of the area taken in both the images is relatively small. The limitation of using texture extraction method is that for any desired area or regions it is an elusive job to clearly visualize the disparity between stereo image pairs. Lastly, the proposed method named as QSPDE overcomes to figure out all the difficulties coming in the way to estimate the clear disparity and presents a new technique for decipherable visualization of the two stereo image pairs.

VI. EXPERIMENTAL RESULTS

For the experiment, few samples of stereo image pairs of the same scene which is obtained from left camera and right camera respectively being placed on stereoscopic rig base model is considered. In Fig. 3(b), a pair of epipolar or raster scan is aligned as parallel lines in order to locate the image feature points. Thereafter, the image containing the pair of epipolar horizontal lines are divided into smaller windows. Now, a particular window size in chosen in the left camera image as shown in Fig. 3(a). This window size image is then compared with the right camera image containing the epipolar lines or constraints. Hence, a disparity is visualized between the two images. Similar method is now applied on another image scene as shown in Fig. 3(c) and Fig. 3(d). At this moment, it is bit difficult to visualize the horizontal disparity using correlation method of stereo image pairs.

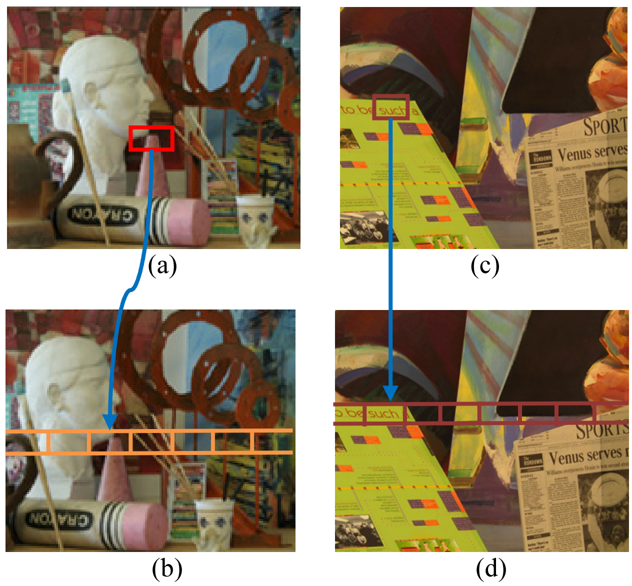
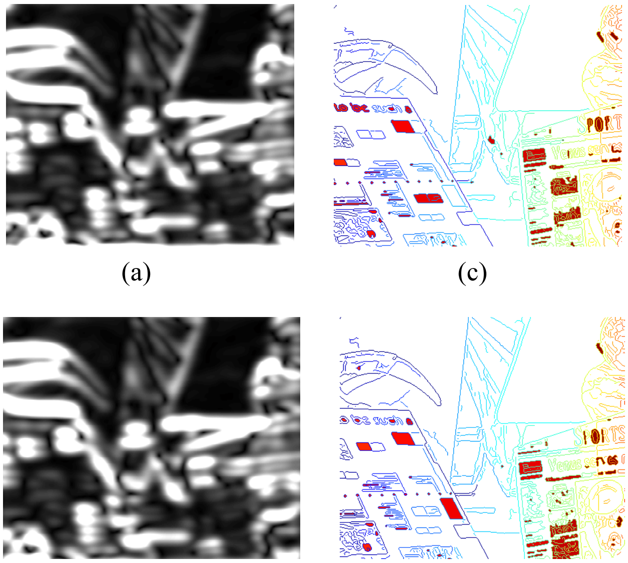


Fig. 3. Camera color image: left (a) and (c), right (b) and (d).

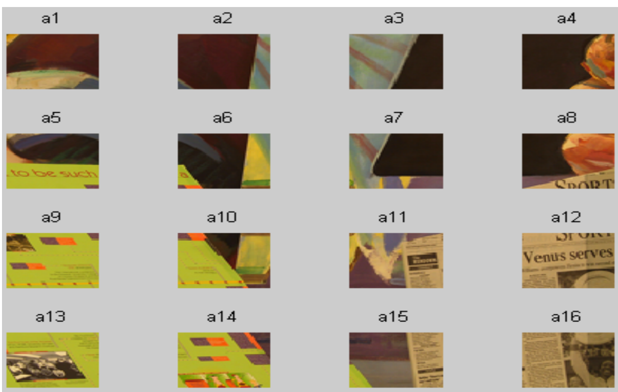
The above mentioned experiment is done by taking area based correlation method. Now, let us consider feature based correlation which includes edge detection and texture extraction methods. Fig. 4(a), (b) and Fig. 4(c), (d) show the texture extraction by using 'Gabor' and 'Canny' filters of Fig. 3(c) and Fig. 3(d) respectively. Looking at these figures, it is analyzed that horizontal disparity estimation is little difficult to distinguish clearly. Considering both area based and feature based correlation methods, QSPDE is proposed which is basically area based stereo-matching but not limited to choose a particular size window.



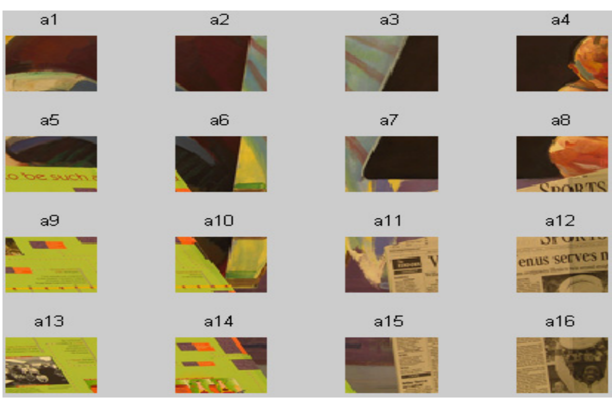
(a) (c)

(b) (d)

Fig. 4. ‘Gabor’ and ‘Canny’ filter image from Fig. 4(c) and Fig. 4(d) respectively: (a) and (c) left, (b) and (d) right.



(a)



(b)

Fig. 5. Quadtree segmentation: (a) left camera image, (b) right camera image.

Fig. 5(a) and Fig. 5(b) show the quadtree segmentation of left camera image and right camera image respectively obtained by using MATLAB 7.4.0. Now, let us choose some pixels like ‘a8’, ‘a10’ and ‘a12’ of left camera image and compare it with same pixels of right camera image respectively. It is observed that the visualization of the horizontal disparity between both images becomes easier in comparison to the feature based stereo-matching methods. Thereafter, if the coordinates of those pixels obtained from left camera image and right camera image are compared to each other, it is observed that the QSPDE method is able to get the clear disparity of every pixel in more easy and robust way as shown in Table II.

TABLE II
PIXEL’S DISPARITY ESTIMATION

Pixel's Number	Left Camera Image(L)	Right Camera Image(R)	Pixel's Disparity |L-R|
‘a8’	363	375	12
‘a10’	169	181	12
‘a12’	332	344	12

This proposed method is valid for any pixel which is selected and compared between both stereo images. Initially, each stereo image pairs is observed and use correlation method for easy disparity visualization. If it is unable to get clear disparity between two images then in that case QSPDE method is applied. In the proposed method, the two levels of standard quadtree segmentation of stereo image pairs have been done to estimate the disparity. QSPDE method has got better flexibility to further divide each four smaller blocks or pixels into another four sub-pixels to distinguish the horizontal disparity at micro-level.

VII. CONCLUSIONS

The visualization of horizontal disparity using ‘Gabor’ and ‘Canny’ filters plays crucial role for the determination of the geometrical differences between two stereo image pairs of the same scene taken at slightly different positions. Till now, correlation based stereo-matching method has been used in which a selected area of an image is taken in both the images to distinguish the disparity.

Since, correlation method is very time consuming operation and is only valid for few stereo images, so it is inevitable to simplify the visualization algorithm without affecting the quality of the stereo images. For this purpose, segment based stereo-matching are widely used. A popular approach is to partition the image into smaller segments and then block matching algorithm is performed to visualize the disparity.

In this paper, a novel method for estimating the disparity is proposed by dividing an image of any size into smaller pixels. This method is named as "Quadtree Segmentation of Pixels Disparity Estimation (QSPDE)". QSPDE is relevant to any stereo image pairs and better way for distinguishing the horizontal disparity with much more clarity and higher effectiveness.

ACKNOWLEDGEMENT

This work was supported by the Culture Technology Joint Research Center Project of the Korea Creative Content Agency.

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