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Ghost Removal in High Dynamic Range Images using SVD and Disparity Map

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ABSTRACT: A standard and commonly used approach to obtain an HDR image is the multiple exposures fusion technique which consists of combining multiple images of the same scene with varying exposure times. If the scene is not static during the sequence acquisition, ghosting artefacts occur in the final HDR image. Removal of ghosting artefacts is an important issue. Several methods have been developed in literature to solve the ghost problem in dynamic scenes. In singular value decomposition (SVD) method of HDR generation, the second biggest singular values extracted over local spatio-temporal neighbourhoods can be used for ghost region detection. The disparity mapping technique can be effectively used for ghost detection giving better results. In this paper disparity map method is incorporated with the SVD technique of ghost removal to obtain a ghost free HDR image. A comparative study of SVD and disparity map based ghost detection methods are also carried out.

KEYWORDS: High dynamic range imaging, Multiple exposure fusion, Ghosting artefacts, Singular Value Decomposition, Disparity map.

I. INTRODUCTION

The real world scenes have a very wide range of luminance levels. But the ordinary cameras are not capable of capturing the true dynamic range of a natural scene. A technique known as High Dynamic Range (HDR) imaging is generally used to enhance the dynamic range of the captured image,. HDR imaging is the process of capturing scenes with larger intensity range than what conventional sensors can capture. It can faithfully capture the details in dark and bright part of the scene simultaneously.

Dynamic range (DR) of a scene is defined as the range from the lowest to the highest light intensity occurring in the scene. It is also known as scene contrast. An image is said to be in high dynamic range if it has fine details in both the bright and dark regions in the image. The dynamic range of real-world scenes can be as high as in the ratio of 100,000:1. Human visual system can process and adapt to a dynamic range of about 50,000:1. The images captured by the cameras can only have dynamic ranges between 300:1 to 1,000:1. These images are therefore considered as low dynamic range (LDR) images. Longer exposures would capture details in the dark areas of a scene while shorter exposures would capture the bright areas of a scene. That is, the details in both the dark and bright areas of a scene are not visible in a single image. Such a type of image is known as LDR image.

High Dynamic Range (HDR) images capture the whole tonal range of real-world scenes, using 32-bit floating-point values to store each colour channel. The use of floating point values gives HDR images several advantages over LDR images. The areas that are too dark are clipped to black and areas that are too bright are clipped to white in an LDR image. Pixel values in an HDR image are normalized between 0.0 and 1.0. Dark and bright areas are assigned different values close to 0.0 and 1.0. Therefore, HDR images can preserve details of a scene having large dynamic range. Another advantage of HDR images is that they preserve optical phenomena such as reflections and refractions. In LDR images, the pixels representing all the bright light sources in a scene are assigned to have the maximum possible integer value and the reflected light should have value less than the light source. In HDR images, the reflected light is assigned with values close but less than 1.0 and the bright source can assume values equal to 1.0. Therefore, HDR images are able to better represent scenes as perceived by human eyes.

High dynamic range (HDR) imaging refers to a set of techniques that allow a greater dynamic range of luminance between the lightest and darkest areas of an image than standard digital imaging techniques. The wide

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dynamic range of HDR images allows representing the wide range of intensity levels found in real scenes. HDR has the following qualities:

(i) High contrast ratio: Bright and dark regions need to be captured.
(ii) High bit depth: To encode values with quantization levels as small as the just noticeable difference; so that no stepping is visible resulting in a smooth intensity gradient.
(iii) Details are preserved: There is no or little clipping due to over- or under-saturation.

To directly capture HDR content, specialized cameras are proposed but these devices are expensive. The commonly used method is to take sequential LDR images at different exposure levels (known as bracketed exposures) and then merge them into an HDR image. This method is known as multiple exposure combination technique.

High dynamic range (HDR) imaging consists of:

(i) HDR recovery or acquisition: In HDR acquisition the true luminance of a scene is captured with a low dynamic range capturing device.
(ii) Tone mapping: To faithfully represent HDR information on a low dynamic range display device that is incapable of reproducing the actual luminance and the true colours.

II.RELATED WORK

The most common method of HDR generation is to take multiple images of the same scene with different exposure times, and combine them into a single HDR image [3]. The basic concept is that each pixel will be properly exposed in at least one image. A single photo is insufficient to record all the details in the scene because, some areas in the photo may be over-exposed and other portions may appear under-exposed ie, details can hardly be seen. The fusion of a set of LDR images can be classified into two main approaches: fusion in the radiance domain and fusion in the image domain.

Fig.1 Multiple exposure images

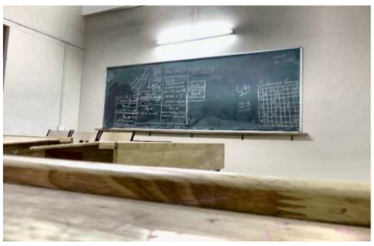

Fig.2 HDR image generated using multiple exposure technique

1. HDR Reconstruction In Radiance Domain

HDR image generation process in radiance domain consists of three steps.

(i) Recover the camera response function to bring the pixel brightness values into radiance values. This function models the effect of non-linearities introduced in the image acquisition process. Different methods can be used for its estimation.
(ii) Then all radiance maps are combined into an HDR image.
(iii) A tone mapping operator is used to make the HDR image displayable on LDR monitors.

HDR image is computed as the weighted average of pixels values across exposures using the camera response function.

$$I_m^{hdr} = \frac{\sum_{n=1}^{N} w(I_m^n)[g^{-1}(I_m^n)/t_n]}{\sum_{n=1}^{N} w(I_m^n)} \quad (1)$$

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where I_m^n is value of pixel *m* of the *n*-th exposure image, *N* is the number of images, t_n is the exposure time of the *n*-th image, and *w* is a weighting function. *w(.)* is assigned to reduce the influence of unreliable pixels. In order to display the obtained HDR image on a low dynamic range device, a tone mapping operator is applied. Tone mapping techniques can be classified into global and local methods.

2. HDR Reconstruction In Image Domain

In this category multiple exposures are combined directly without computing camera response function. These methods combine LDR images by preserving only the best parts of each exposure. Final HDR image is obtained as a weighted average of pixel values across exposures:

$$I_{ij}^{c} = \sum_{k=1}^{N} w(Z_{ij,k}) Z_{ij,k} \tag{2}$$

where I^C is the composite image.
Methods that combine images in the radiance domain are highly relied on accurate estimation of the camera response function, which is sensitive to image noise and misalignment. These methods require tone mapping operators for HDR image reproduction. A true HDR radiance map is obtained in the combination step which contains the whole dynamic range of the captured scene. Methods that combine exposures in the image domain are more efficient since they avoid the estimation of the camera response function and do not require tone mapping. They directly produce a tonemapped-like HDR image. These are the common difference between fusion in image and radiance domain.
Multiple exposure technique suffers from the following problems:

(i) Misalignment: Global camera motion, from hand-held camera for instance, results in misaligned input images that cause the combined HDR image to look blurry. This problem can be solved by placing the camera on a tripod or by using an image registration method. Image registration is the process of transforming different sets of data into one coordinate system. In particular, the median threshold bitmap (MTB) technique [5,6] is an efficient solution. The translation alignment based on median threshold bitmaps [6] is extended with an additional rotation [5].This method is fast and can accurately recover the small displacements between images. Other registration methods based on key points extraction and matching can also be used. The most commonly used key points detectors are Harris corners and SIFT features.

(ii) Ghosting: Moving objects in the scene will appear in different locations in the combined HDR image, creating what are called ghosts or ghosting artefacts. Ghosting artefacts are the most severe limitation of the multiple exposures technique since moving object is unavoidable.

The Fig. 3 denotes three level exposures of the scene with moving object. Those exposures are captured in different time and using different shutter speed. In each image the sun (moving object) is located at a different location leading to ghosting artefact in the resultant HDR image.

Most of the HDR generation methods employ a two-step strategy: ghost detection and ghost removal. Ghost detection methods are based on motion detection. There are two types of motions in a dynamic scene:

(i) a moving object on a static background.
(ii) a moving background with static or dynamic objects. Some of the methods can detect only the first type of motion while others can detect both.

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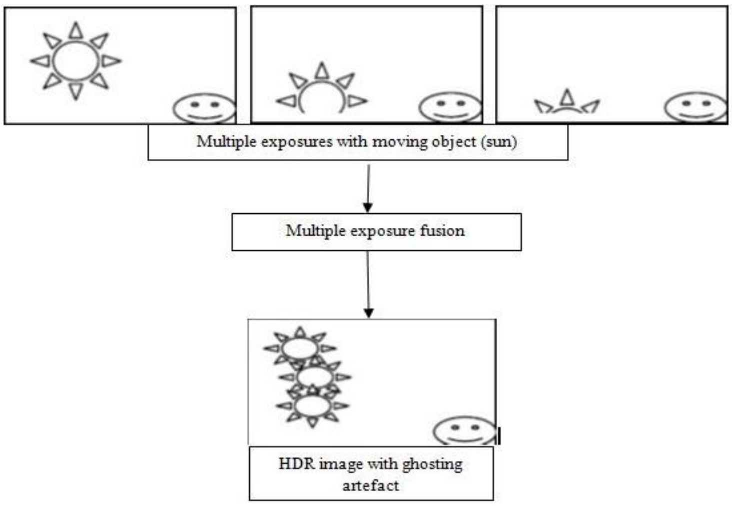

Fig.3 Framework for HDRI with Ghost Artefact

III. SINGULAR VALUE DECOMPOSITION AND DISPARITY MAP

1. Singular value decomposition

To obtain the ghost map for the removal of ghosting artefacts different ghost detection methods [7] are mentioned in literature. Once ghost maps are generated they can be used to remove the ghosting artefacts. Ghost removal methods can be classified into two categories. The first category is to remove ghosting artefacts while keeping a single occurrence of the moving object. The second method will completely remove the moving object in the image. In this paper we consider the singular value decomposition (SVD) method of ghost detection and removal [4] along with disparity map based ghost detection technique. SVD method [8] can transform matrix M into product USV^T. In this method any matrix M can be categorized into three new matrices *U*, *S*, and *V*, in such a way that

$$M_{mxn} = U_{mxm} S_{mxn} {V_{nxn}}^T = \sum_{i=1}^{r} \sigma_i u_i v_i^T \quad (3)$$

Where *U* and *V* are orthogonal matrices and *S* is a diagonal matrix.

Calculating the SVD consists of finding the eigen values and eigenvectors of MM^T and M^TM. The eigenvectors of M^TM make up the columns of *V*, the eigenvectors of MM^T make up the columns of *U*. Also, the singular values in **S** are square roots of eigen values from MM^T or M^TM. The singular values are the diagonal entries of the *S* matrix and are arranged in descending order. The singular values are always real numbers. If the matrix *M* is a real matrix, then *U* and *V* are also real. The matrix *S* can be written as

$$S = \begin{bmatrix} \sigma_1 & 0 & \cdots & 0 & 0 & \dots & 0 \\ 0 & \sigma_2 & \dots & 0 & 0 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_r & 0 & \dots & 0 \\ 0 & 0 & \dots & 0 & \sigma_{r+1} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 0 & 0 & \dots & \sigma_n \\ 0 & 0 & \dots & 0 & 0 & \dots & 0 \end{bmatrix} \quad (4)$$

For $i = 1, 2, \dots, n$, σ_i s are called Singular Values (SV) of matrix M. The singular values are unique and the rank of matrix M is equal to the number of its nonzero singular values. These are some of the properties of singular value decomposition. Also the matrix *A* can be represented by the outer product expansion as the sum of rank one matrices.

$$M = \sigma_1 u_1 v_1^T + \sigma_2 u_2 v_2^T + \dots . + \sigma_r u_r v_r^T \quad (5)$$

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2. Disparity map

Stereo matching is to estimate the disparities between stereo images, which are generated from different viewpoints. This generates the disparity map from a set of two dimensional stereo images.

If we look at the image below we can see an object point X. By following the dotted line from X to OL you see the intersection point with the left hand plane at XL. The same principal applies with the right-hand image plane.

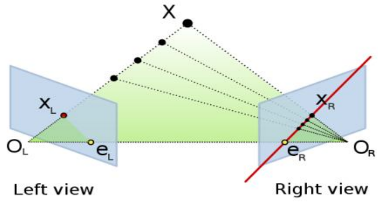

Fig. 4 Disparity map technique for stereo images

If X projects to a point in the left frame XL = (u,v) and to the right frame at XR = (p,q) you can find the disparity for this point as the magnitude of the vector between (u,v) and (p,q). Obviously this process involves choosing a point in the left hand frame and then finding its match (often called the *corresponding point*) in the right hand image. If you were to perform this matching process for every pixel in the left hand image, finding its match in the right hand frame and computing the distance between them you would end up with an image where every pixel contained the distance/disparity value for that pixel in the left image. This image is known as disparity image or disparity map.

In the disparity map, the brighter shades represent more shift and lesser distance from the point of view (camera). The darker shades represent lesser shift and therefore greater distance from the camera. When performing stereo matching, image rectification should be done to find out the matching pixels in the left and right image.

This technique can be used to obtain the ghost map for HDR generation by using multiple exposed images captured from a single viewpoint instead of stereo images. Since the differently exposed images are captured from a viewpoint there is no need for image rectification.

IV. HDR GENERATION USING DISPARITY MAP AND SINGULAR VALUE DECOMPOSITION

In this paper we first consider singular value decomposition method of ghost detection and removal [4]. In this method, given a set of multiple exposed low dynamic range images for a set of P consecutive exposures define a spatio-temporal neighbourhood for every pixel. This is then rearranged to form a matrix M such that each of its columns shows the brightness values of a single pixel in different exposures. The singular values of these matrices are then calculated using singular value decomposition as discussed in the previous section. For ghost free area, all the rows of matrix M are linearly dependent, therefore the rank of the matrix is one. Using the property of SVD, rank of matrix is equal to the number of non-zero singular values. Therefore, rank one matrix has a single non-zero singular value. In other words, for a ghost free pixel the second largest singular value should be small ideally equal to zero while for ghost areas this value should be large. Hence, the second biggest singular value can be used to obtain a ghost map for each set of P consecutive exposures. Finally, a global ghost map is obtained as the sum of thresholded individual ghost maps.

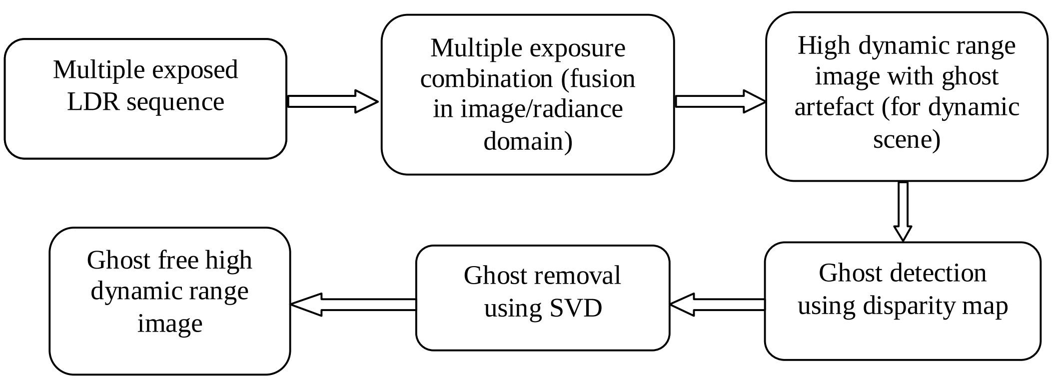

Fig. 5 Block diagram of proposed method

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Once the ghost map is obtained it can be used for ghost removal. Using SVD any matrix can be written as the weighted sum of rank one matrices as in equation (5). The first term of decomposition captures the static part of a scene while the remaining terms corresponds to the moving parts. Therefore, a ghost free HDR image can be reconstructed using singular value decomposition by keeping only the first term of decomposition. Also ghost free HDR image can be obtained as the weighted average of singular values of the input exposures. Weights are calculated from the global ghost map. Large weights are assigned to ghost free area and zero weights for ghost areas.

But it is observed that some of the actual ghost pixels are incorrectly identified as non-ghost pixels and vice-versa in the ghost map. Therefore, disparity map based ghost detection where the disparities between two consecutive images captured at varying exposures are computed. As mentioned earlier, the disparity mapping technique used for stereo images can be used to obtain ghost map from multiple exposed low dynamic range images. The multiple exposed images are captured using a camera from a particular view point so there is no need for image rectification. Firstly, the disparity maps between each consecutive input image are calculated. Then average of absolute values of disparity maps is taken. Some post-processing operations, such as hole filling and removing small objects from the disparity map that are not part of the ghost regions, are performed. The disparity map can then be used with SVD ghost removal technique to obtain a ghost free HDR image.

V. EXPERIMENTAL RESULTS

We consider a sequence of seven exposures with moving objects in the scene. The sequence of exposures and the resulting HDR image with ghosting artefacts are shown in figure 6 and 7 respectively.

Fig. 6 Input sequences

Fig. 7 HDR image generated containing ghosts.

Several ghost maps are detected for each set of P consecutive exposures and are finally combined into a global ghost map as shown in Fig.8 (a) and (b) respectively. In our experiments we selected P=3 and size of the spatial window (d) is set to 2 in each exposure. These five ghost maps are combined to form the global ghost map which is the sum of thresholded individual ghost maps. Global ghost map is shown in Fig.8(b). The HDR image generated using SVD is shown in Fig. 8(c).

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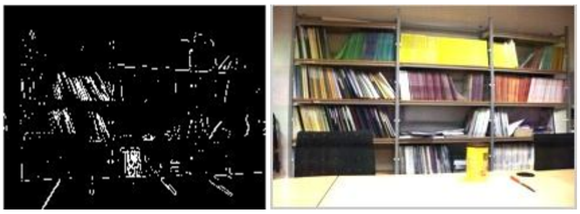
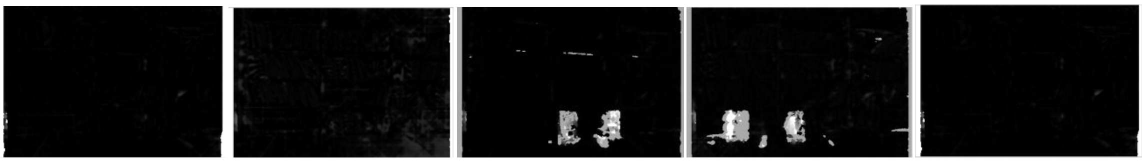
(a)



(b) (c)

Fig. 8 Ghost detection based on SVD(a) Five ghost maps (b) Global ghost map (c) Ghost free HDR image

The disparity maps obtained from the consecutive two images are shown in Fig. 9(a). The average of disparity maps and the map after post processing operations are shown in Fig.9(b) and (c) respectively. Fig. 9(d) shown a ground truth which the manually segmented ghost map are used for the evaluation of ghost detection methods. The HDR image generated using disparity map based ghost detection is shown in Fig. 9(e).



(a)

(b) (c) (d) (e)

Fig. 9 Disparity map based ghost detection (a) Disparity maps (b) Average of disparity maps(c) After post processing (d) Ground truth (e) Ghost free HDR image

Table1: Quantitative evaluation of ghost detection methods

	SVD based (%)	Disparity map based (%)
Sensitivity	**15.45**	**87.74**
Specificity	**94.77**	**98.19**
Accuracy	**90.48**	**97.63**

To quantitatively evaluate the ghost detection methods two parameters namely, sensitivity and specificity can be used. Sensitivity indicates the percentage of ghost pixels that are correctly identified as ghosts and specificity indicates the percentage of non-ghost pixels that are correctly classified as non-ghost. Therefore, a good detection method should have high values for sensitivity and specificity. By using singular value decomposition of ghost detection it is observed from the Table1 that only 15% of the ghost pixels are correctly identified as ghosts ie, sensitivity value is very low. From the Table1 we can see that the disparity map based method of ghost detection gives much higher values for sensitivity and specificity. Also, the accuracy of disparity map based method of ghost

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detection is 97% whereas the accuracy of SVD based ghost detection is only 90%. The time required for the computation of ghost map using SVD is much high compared to disparity map based ghost detection.

VI. CONCLUSION

In this paper, singular value decomposition and disparity map based ghost detection and removal are proposed for ghost free HDR image. In SVD based ghost detection second largest singular values are used for obtaining the ghost map. The disparity mapping technique that is usually used for stereo images can be used for ghost detection. SVD ghost removal method is used in both the cases for the reconstruction of ghost free HDR image. A comparative study of the two ghost detection methods are performed using parameters like sensitivity, specificity and elapsed time. It is observed that ghost detection using disparity mapping technique gives better results compared to SVD based ghost detection. As a result a better quality HDR image can be obtained using disparity map based ghost detection combined with singular value decomposition ghost removal technique.

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