A Novel Technique for Non-overlapping Image Mosaicing based on Pyramid Method

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***Abstract* – Image mosaicing has been used in various arenas of image engineering. The main purpose of this research work is to develop a novel blending algorithm for mosaicing of two non-overlapping images with minimum distortion and no visible seam. In the proposed method, images are mosaiced using the pyramid technique and Savitzky-Golay filter is used for smoothing the seam between the images in the generated mosaic. Savitzky-Golay filter, is based on the least square fitting of polynomial functions of image intensities. It effectively reduces the noise and preserves the image information content resulting in a visually pleasing mosaiced image. The results and comparative analysis show the effectiveness of the proposed method.**

***Keywords* – Image blending; mosaicing; pyramid algorithm; Savitzky-Golay filter.**

I. INTRODUCTION

Image mosaicing is being widely used in digital image processing, remote sensing [1], computer vision and medical applications. In computer graphics or advertising, it is frequently used for creating synthetic images from non-overlapping as well as unrelated images. Image mosaicing, in general, is the process of assembling two or more images in order to generate visually appealing image that is more informative and has a large field of view (FOV) as compared to the individual input images. The mosaiced image should have following two properties: firstly, geometrically and photometrically the mosaic should be similar to the input images and secondly the transition from one image to the other should be smooth.

A difficulty which often arises while mosaicing two images of a scene, is the formation of visible 'edge' at the overlapping part. Various factors such as camera position, the source of illumination etc. may intervene and produce discrepancies in the intensity levels of the input images, giving rise to obstructive 'edges'. This makes the final mosaic appear unpleasant. Thus, an efficient mosaicing method is required to mitigate this detectable effect.

Image mosaicing typically consists of two stages, namely, image registration [2], [3] and image blending [4]. The goal of the first stage is to identify and register the corresponding points in the overlapping parts of the two input images. In the second step, the aligned image intensities are blended seamlessly using appropriate blending algorithms [4]–[8]. However, there are many applications in computer vision and computer graphics that do not require image registration. In such cases, arbitrary images are blended to produce special visual effects. In this paper, focus is on seamless blending of unrelated input images

In literature [9], image blending methods are categorized in two main classes. *Transition smoothing methods* concentrate on minimizing the visual impact of the seam introduced in the overlapping region by smoothing it. A weighted mask with varying coefficients is used for each of the input images. Mosaiced image is the combination of these input images with different value of weighting coefficients [10]. Image pyramids [11] are quite useful for blending image features at different levels of resolution. Low frequency components and high frequency components are separated and treated independently by applying smoothing function. This provides a gradual transition around the seam. In previous works, multiresolution pyramid representation has been used extensively in image blending. Recently multiresolution blending has been used for gradient domain blending [12] and wavelet domain [7]. Gradient-domain based image stitching (GIST) and blending has been proposed in [12] that minimizes photometric inconsistencies. The authors in [7] have applied the idea of multiresolution for deriving blending function from an energy minimization model. The smoothness of the seam near the overlapped region of mosaiced image is thus balanced using this approach. *Optimal seam techniques* [4], [5], [9] & [13] determine the best boundary in the overlapping region that minimizes the intensity differences between two input images. Each image is then placed on the corresponding side of the final image mosaic. If the difference between input images is zero, then no visible seam exists in the final mosaic. In recent few years, a new method based on the use of graph cuts [14] gained wide popularity. A specialized graph is constructed for representation of energy function, such that graph having minimum cut represents minimized energy. Related to this, a novel method based on the combination of watershed segmentation and graph cuts has been presented in [15] for image blending. Use of watershed segmentation limits the search space required for determining contribution boundaries, whereas graph cuts ensures the optimal solution for every intersection region. Development of fast and robust image mosaicing methods has been a prime target for the image processing researchers. Due to the non-existence of a standard test data there has been a need for subjective as well as objective quality evaluation of mosaiced images obtained from the existing algorithms.

In this work an image blending algorithm is developed for creation of image mosaics from non-overlapping images while improving the quality of mosaic by reducing the noise content. Pyramid method has been used for mosaicing two unrelated images. A filter with noise reduction property is being used for smoothing the seam and for reducing the noise in the synthesized mosaiced image. A quantitative quality assessment measure has been presented for the evaluation of mosaiced image quality.

This paper is structured in five sections. Section II provides basic notions of pyramid method to give the necessary background information used in image mosaicing. In Section III proposed blending method is described. Results and qualitative analyses have been discussed in Section IV. Finally the paper is concluded in Section V.

II. Pyramid Method

a) Image pyramid

Image pyramid is one of the popular data structures used for the representation of image information. An image pyramid consists of a sequence of bandpass or lowpass decomposed copies of the original image, each having image information of a different resolution and sample density [16]. Fig. 1 shows the different levels of decomposition. Each subsequent level has half the resolution and quarter numbers of pixels of its previous level.

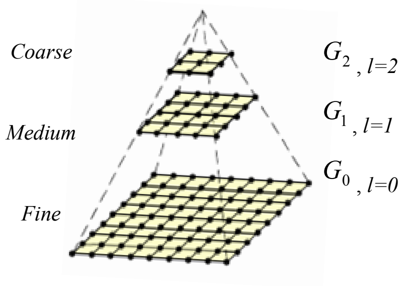


Fig. 1 An image pyramid.

In computer vision, Laplacian pyramid [11] is the most widely used pyramid structure. It is constructed by blurring and subsampling the original image by using a scale factor of two. Each level of the pyramid is related to the adjacent level by a scale factor (sampling rate). $r = 2$, Such pyramids are referred as *octave pyramid* [17]. Lowpass filtered images are generally called *Gaussian images*, whereas highpass filtered images are called *Laplacian images*. Fig. 2 (a) and Fig. 2 (b) are the examples of such pyramid structures. G_0, is the original image that forms the bottom level of the pyramid. G_1 is the next level obtained after lowpass filtering and subsampling G_0 by a factor 2. In the similar way G_2 is formed as a reduced version of G_1 and is repeated for N levels. The pyramid construction process is equivalent to convolution of a set of Gaussian-like weighing functions with the original image. The generated lowpass images resemble Gaussian density function and hence the complete set is called *a Gaussian pyramid.* For $0 < l < N$

$$G_l(i,j) = \sum\sum w(m,n) G_{l-1}(2i+m, 2j+n) \quad (1)$$

more conveniently this operation is simply written as

$$G_l = REDUCE\,[G_{l-1}] \quad (2)$$

The weighting function $w(m,n)$ also called generating kernel should satisfy following four requirements:

i. It should be separable $w(m,n) = \hat{w}(m)\hat{w}(n)$
ii. 1D function $\hat{w}$ should be symmetric $\hat{w}(0) = a$, $\hat{w}(-1) = \hat{w}(1) = b$, $\hat{w}(-2) = \hat{w}(2) = c$
iii. $\hat{w}$ should be normalized $a + 2b + 2c = 1$
iv. Each level l node should equally contribute to the next level $l+1$ nodes.

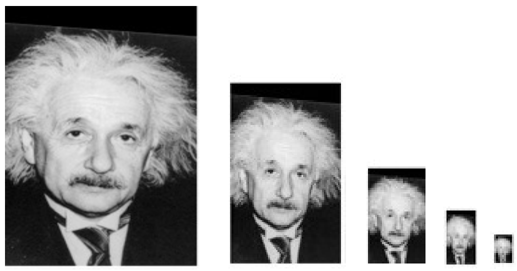
For some purposes bandpass images are required rather than lowpass images. In the pyramid, each lowpass level is subtracted from the next level to obtain these bandpass images. Since the successive levels have different sample densities, interpolation of new sample values is required before the subtraction of one level from the next lower level. REDUCE process is reversed to achieve the interpolation. It is now named as an EXPAND process. It can be written as

$$G_{l,k}(i,j) = 4\sum_{m}\sum_{n=-2}^{2} G_{l,k-1}\left(\frac{2i+m}{2}, \frac{2j+n}{2}\right), \; for\ k = 0 \quad (3)$$

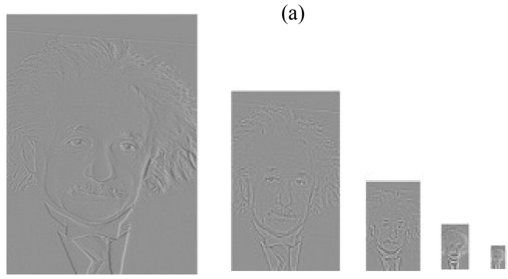
$G_{l,k}$ is the image obtained by k times expanding G_l . With each iteration of expand operation the size of the image is doubled. Different levels of this bandpass pyramid can be expressed in terms of lowpass levels as

$$\begin{aligned} L_l &= G_l - EXPAND[G_{l+1}] \\ &= G_l - G_{l+1,1} \end{aligned} \quad (4)$$

By convolution of the original image with a difference of two Gaussians the values of bandpass pyramid can be



(a)



(b)

Fig. 2 Pyramids (a) Gaussian (b) Laplacian obtained, which resemble Laplacian operator. For the same reason this pyramid is called *a Laplacian pyramid.* Repeated REDUCE and EXPAND process generate different levels of pyramid with fewer steps.

b) Pyramid blending

In image pyramid approach, two issues are of major concern; effective decomposition of images into different resolution levels and smooth blending of images at every decomposed level. Image mosaicing using pyramid method comprises of two main steps: The input images are first decomposed into different levels with varying sample density and resolution by means of pyramid Laplacian operators. Then an appropriate function is applied for the blending of images at the overlapping portion in the final mosaic.

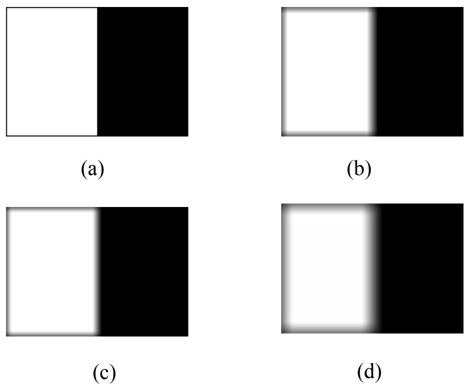


Fig. 3 Mask (a) Original, (b) Averaging, (c) Circular averaging, (d) Savitzky - Golay filtering

Pyramid blending smoothens the two frequency bands individually. It blends the low frequency component gradually over a wide area around the seam, while maintaining the transition in the high frequency band sharp over a narrow area around the seam. There are various smoothing filters used for smoothing of images. Mask of different smoothing filters has been shown in Fig. 3. The process of averaging filter is equivalent to low pass filtering. An average filter smooths the image by replacing each pixel with the average of neighboring pixel intensities. In circular averaging the kernel is a square matrix of side (2*radius+1), the kernel reaches equally far around a given pixel within the square matrix. Savitzky-Golay filter, also known as digital smoothing polynomial filter that increases the signal-to-noise ratio without greatly degrading the quality of an image. Higher level of smoothing, without attenuation can be achieved by using higher degree polynomial.

III. Proposed Framework

The main aim of blending algorithm is to adjust the intensity values around the overlapping region to conceal the seam. A blending algorithm is proposed for the mosaicing of two non-overlapping unrelated images. The input images are mosaiced using pyramid method and blending is carried out using Savitzky-Golay filter.

Smoothing is the major operation of blending in image mosaicing. However, a possibility of loss of information content of the image is there in smoothing. Savitzky-Golay filter is applied for smoothing the seam while retaining the image information.

Savitzky-Golay filter

It is a type of 1-D linear lowpass filter, formulated by using least squares fitting of different polynomial functions to a particular set of data points. A 2-D extension of Savitzky-Golay filter is being incorporated for the smoothing of image seam [18]. For each position (i, j) in the image, the output $g(i, j)$ of the S-G filter is derived by fitting polynomial $p_{i,j}$ to the data points of the original image. The output image is expressed as

$$g(i, j) = \sum_{q=1}^{(2M+1)(2N+1)} \alpha_q f_{i+m(q), j+n(q)} \quad (5)$$

$g(i, j)$ is the linear combination of intensities $f(i, j)$ of the image. α is the coefficient of S-G filter.

Flow diagram of the proposed algorithm has been shown in Fig. 4.

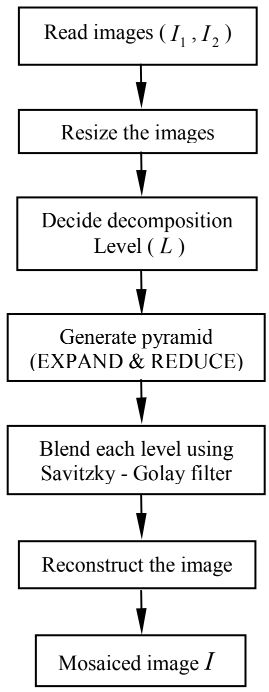


Fig. 4 Flowchart of proposed algorithm

In this approach, we generate an image mosaic I from two input images I_1 and I_2 . Firstly each image is decomposed into a set of frequency bands. Lowpass filters are utilized to generate set of images, $G_0, G_1, \ldots, G_N$ with reduced bandlimit for each octave step. The input image I_1 and I_2 are filtered and subsampled repeatedly to generate the set of reduced resolution images. These comprise the sequence of lowpass filtered copies of I_1 and I_2 with decreased bandwidth, one octave each step.

By subtracting each lowpass image from its previous level image, a set of bandpass images $L_0, L_1, \ldots, L_N$ is obtained. The final mosaic is reconstructed by summing all the bandpass sequence images.

IV. RESULTS AND DISCUSSION

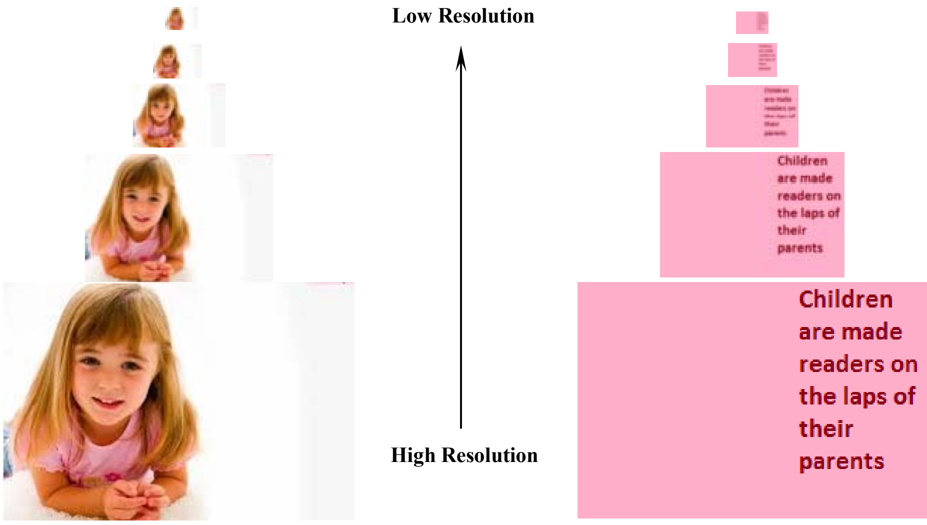
This section deals with the performance evaluation of the proposed algorithm using S-G filter for pyramid based image mosaicing. The input image pyramids at multiple resolutions are shown in Fig. 5. Fig. 6 (a) shows the blending result using feathering technique. The union of the two input images generated after incorporating the proposed algorithm is shown in Fig. 6 (b). Where, the transition region between the two unrelated input images is made gradual by means of S-G filter. This process results in the smoothening of noise content and preservation of the information content of individual images. The effect of smoothing basically depends on the order of the polynomial of the filter.

A single and objective criterion is not there to identify highest visual quality of an image because the 'quality' concept comprises of various cognitive aspects. The qualitative assessment results, obtained by using different smoothing filters, have been presented in Table I. From the table it is clear that the performance of S-G filter is better than that of other filters. Quality assessment parameters can be compared for different filters. Though there is no significant improvement in structural content of resultant images, still the peak signal to noise ratio (PSNR), standard deviation and entropy are found to be superior as compared to other filters.

TABLE I. QUALITATIVE ASSESSMENT

Filters	Quality assessment parameters			
	PSNR (dB)	***Standard deviation***	***Entropy***	***Structural content***
Gaussian	49.0409	60.7469	3.3665	0.9986
Averaging	49.1321	60.7601	3.3694	0.9986
Circular average	49.5210	60.8216	3.4292	0.9996
Savitzky - Golay	50.5722	60.8898	3.4350	0.9997

Visual examination of these results is acceptable, but the qualitative evaluation of images is necessary for quality assessment of mosaiced image. The robustness of the



(a) (b)

Fig. 5 Input image pyramid with different levels of resolution

(a) (b)

Fig. 6 Mosaiced image (a) Feathering (b) Proposed method proposed image mosaicing technique is properly justified by means of some vital quantitative quality assessment parameters and the indices obtained are given in a Table II. The proposed technique produces the mosaiced images with improved PSNR value, information content, blur metric and Edge Based Contrast Measure (EBCM) as compared to the feathering technique for blending.

TABLE II. QUALITATIVE ASSESSMENT

Blending algorithms	Quality assessment parameters			
	PSNR (dB)	***Entropy***	***Blur metric***	***EBCM***
Feathering	15.4029	5.9585	0.2424	180.1148
Proposed	15.6886	6.2056	0.2227	184.9643

A second set of images has been taken to show the effect of the proposed blending algorithm. The images selected are of different colors so that the differences can be seen clearly. The input image pyramids at multiple resolutions are shown in Fig. 7. Fig. 8 (a) represents the mosaiced image generated by using feathering. The mosaiced image obtained using proposed algorithm is shown in Fig. 8 (b). This process results in the smoothening of noise content and preservation of the information content of individual images.

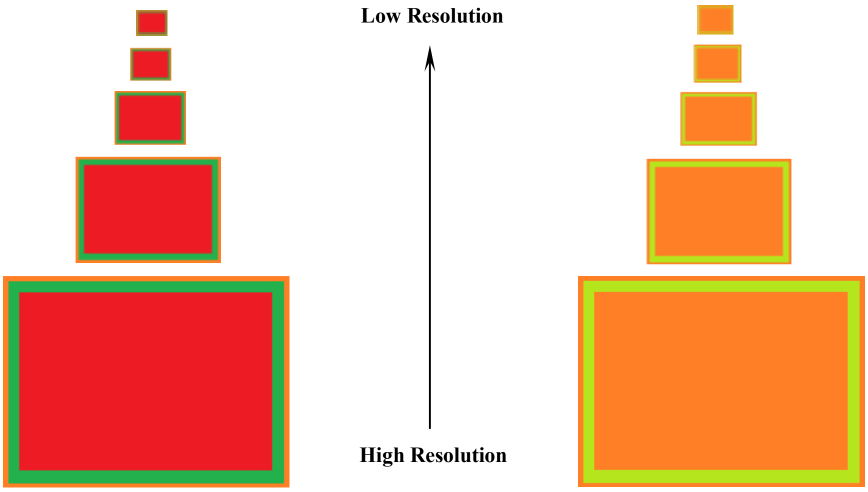
Table III represents the parameter values for the second set of images, when different filters are used for smoothing. From the table, the superiority of the proposed algorithm can be justified with respect to filters like Gaussian, averaging circular averaging, and S-G filter. The values of PSNR, standard deviation, entropy and structural content are high for S-G filter. Thus it can be seen that S-G filter gives better performance as compared to the rest of the smoothing filters.

TABLE III. QUALITATIVE ASSESSMENT

Filters	Quality assessment parameters			
	PSNR (dB)	***Standard deviation***	***Entropy***	***Structural content***
Gaussian	23.4521	38.1228	3.8482	0.9649
Averaging	34.4221	33.6446	3.4759	1.0036
Circular average	37.1548	33.4122	3.6160	1.0117
Savitzky - Golay	45.9760	33.7803	3.6577	1.0255

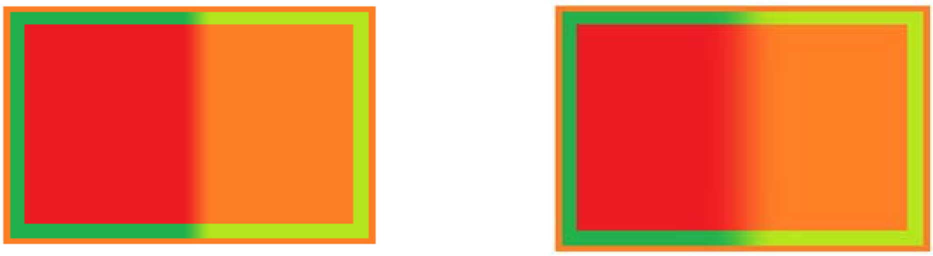
TABLE IV. QUALITATIVE ASSESSMENT

Blending algorithms	Quality assessment parameters			
	PSNR (dB)	***Entropy***	***Blur metric***	***EBCM***
Feathering	23.7499	2.2006	0.1990	129.9825
Proposed	28.6264	3.6672	0.1825	131.8715



(a) (b)

Fig. 7 Input image pyramid with different levels of resolution



(a) (b)

Fig. 8 Mosaiced image (a) Feathering (b) Proposed method

Table IV presents a qualitative analysis of an existing algorithms and the proposed algorithm for blending. PSNR, entropy and EBCM are increasing, which shows the better quality of mosaiced image. However, the value of blur metric is decreasing that shows the smoothing of the image. These results show that smoothing is there but information contents of the image are preserved.

V. Conclusion

We have proposed a new algorithm for mosaicing of two non-overlapping images. A novel aspect is the use of the pyramid method with Savitzky-Golay filter in mosaicing. The mosaicing step is based on pyramid method. For blending at the transition region, Savitzky-Golay filter has been used. Firstly, a set of decomposed levels with varying resolution and sample density are generated. In the next step, blending in each decomposed level is performed using Savitzky-Golay filter. After blending, the mosaiced image is reconstructed. The use of this filter reduces the noise and preserves the image information content. The proposed method is compared with the existing blending technique which exhibits better results.

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