Image Stitching and Blending of Dunhuang Murals Based on Image Pyramid

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Abstract. It is a feasible and meaningful way to preserve the precious murals by using digitization technology. However, it may need to stitch multiple images to get a complete mural panorama. It poses great challenges to stitch and blend these multiple images in a seamless and visually pleasant way. In this paper, we propose an image stitching and blending method based on image pyramid, including Gaussian and Laplacian pyramid, for obtaining a natural stitched images of Dunhuang murals. In special, Gaussian pyramid is used to down-sample the images and get multiple images of different scales through using Gaussian filters. Laplacian pyramid is applied to generate the difference image between each levels of the Gaussian pyramid. Finally, the images can be blended in an adjustable way by specifying the weights of different images. In this way, the stitched images can be presented with reasonable image fusion. Through using the real Dunhuang murals images, the efficiency of the proposed method has been validated.

1. Introduction

Dunhuang grottoes are such important cultural and historical relics, however, the murals are being destroyed mainly resulted from experimental changes. Therefore, the protection of grottoes and murals has always been an important issue. Digitization technology is a feasible approach to preserve the mural information as faithfully as possible. With respect to these digital murals images, many researches such as murals restoration \cite{1-4} have been studied. However, due to large size of the real murals, it is necessary to utilize multiple images for obtaining a complete mural panorama. Therefore, how to stitch and blend multiple digital images of Dunhuang murals into a panorama in a seamless and visually pleasant way is also a critical topic.

Image stitching is the process of generating a panorama by using multiple input images with overlapping fields. The direct way to stitch these images is based on the same contents of the overlapping fields, however, it will cause a seam between two images, and the stitched image may be uncoordinated due to the different brightness of images and so on. Therefore, image blending is necessary to solve the above problems. Image blending is the process of changing one image to fit another image. However, in some cases, two images need to be coordinated for achieving a better result.

Gradient domain image processing methods \cite{5-10} have been widely used. One of the most notable step of these methods is to construct and then solve a Poisson equation for each pixel of the image. It needs to take a lot of time and memory to compute. Therefore, some researches \cite{11-15} intended to improve the speed and performance. For example, Shi et al. \cite{11} have proposed an improved algorithm called PIFB to accelerate the calculation speed through using feature blocks obtained from

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the original image in the process of image stitching. The approaches based on Poisson equation is only one of the common methods to solve the image processing problems. Another alternative approach is based on image pyramid [16], which is used for multi-scale representation of images. Various pyramids can be constructed for image stitching and blending. In this paper, Gaussian and Laplacian pyramid are used to construct image pyramid and then blend images in an adjustable way for obtaining a reasonable image fusion.

In this paper, we focus on the image stitching and blending of Dunhuang murals. Because the original images are high fidelity and definition, the overlapping area of the two images is easier to determine, and the seam is determined as the middle line of the overlapping area. In other words, the determination of the seam is not the study point of our paper. In addition, the image stitching of multiple images can be simplified into the stitching of two images. Therefore, we only focus on the image stitching and blending of two images with a determined seam. To address this problem, an image stitching and blending method based on image pyramid is proposed. Specially, the Gaussian pyramid is used to generate the multi-scale representation of the images, and the Laplacian pyramid is applied to generate the difference image of two adjacent levels in the Gaussian pyramid. Finally, by setting the weights to represent the importance of different images, we can obtain the final image as we intend to.

The main contributions of the paper are as follows:

- Based on image pyramid including Gaussian and Laplacian pyramid, an image stitching and blending method for Dunhuang murals is proposed.
- Gaussian and Laplacian pyramid are used to construct the multi-scale representations of the images in different levels. The final image can be adjusted by specifying the weights of different images, rather than only based on one of the images.
- The real Dunhuang murals are used to validate the efficiency and performance of the proposed image stitching and blending method.

The remainder of this paper is organized as follows. Section 2 described the proposed image stitching and blending method of Dunhuang murals. Section 3 presents the experimental results of real Dunhuang murals to validate the efficiency of the proposed method. Section 4 is the conclusion of the paper.

2. The proposed image stitching and blending method

In this section, the proposed image stitching and blending method based on image pyramid is described in detail. We first introduce the Gaussian pyramid and Laplacian pyramid, respectively. And then the proposed image stitching and blending methods is described.

2.1. Gaussian Pyramid

Gaussian pyramid [16, 17] is used to down-sample the images and then represent the images at multiple scales by using Gaussian filters. In other words, through using Gaussian smoothing and subsampling, the Gaussian image of level \( l+1 \) can be obtained according to the image of level \( l \). In addition, the image in the pyramid is down-sampled by a factor of 2 to get the images of next level until achieving the maximum level \( L \). Assuming that the original image is the image of level 0 in the Gaussian pyramid, \( GP_0 \). The pyramid image at level \( l \) (\( 0 < l < L \)) is represent as \( GP_l \), which can be obtained based on the pyramid image of level \( l-1 \), \( GP_{l-1} \):

\[
GP_l = \text{REDUCE}(GP_{l-1})
\]

(1)

where \( \text{REDUCE} \) function is represented as two operations including Gaussian smoothing and subsampling.

As we can see from the above description, there is a most important parameter that we should be determined, i.e., the maximum level \( L \) of Gaussian pyramid. In other words, the size of the pyramid image at level \( L \), \( GP_L \), is minimum. The size of \( GP_L \) is \( 2\times2 \) in general, which is a relatively low resolution of the image. However, it is impossible to down-sample the image to \( 2\times2 \) due to the width
and height of the original image are always unequal. Therefore, it is necessary to specify the maximum level to limit the number of down-sampling iterations. In the paper, the maximum level $L$ is calculated according to the following equation.

$$L = \log_2(\min(W, H)) - 1$$

(2)

where $W$ and $H$ are the width and height of the $GP_0$, respectively. It is noted that the maximum level $L$ is positive integer and equals to the integer part of equation (2). For example, when the size of $GP_0$ is $40 \times 50$, the $L$ will be set to 4.

Specially, the pyramid image at level $L$ is calculated according to the following equation:

$$GP_l = \begin{cases} GP_0, & l = 0 \\ \text{REDUCE}(GP_{l-1}), & 0 < l \leq L \end{cases}$$

(3)

According to the equations (2) and (3), the Gaussian pyramid can be constructed in a reasonable way.

2.2. Laplacian Pyramid

Based on the Gaussian pyramid, the Laplacian pyramid [18-20] is used to reconstruct the un-sampled images between two levels, i.e., generate the difference image between two adjacent levels. Therefore, the Gaussian pyramid and the Laplacian pyramid have the same levels. The pyramid image of Laplacian pyramid at level $l$ can be obtained and expressed as follows:

$$LP_l = GP_l - \text{EXPAND}(GP_{l+1})$$

(4)

where $\text{EXPAND}$ function represents the up-sampling operation which is mainly used to enlarge the pyramid image at level $l+1$ of Gaussian pyramid.

With respect to the image at the maximum level $L$ of the Gaussian pyramid, it does not have difference image, so the pyramid image at level $L$ of Laplacian pyramid, $LP_L$, is the same as the pyramid image at level $L$ of Gaussian pyramid. Therefore, the pyramid image of Laplacian pyramid at each level can be expressed as follows:

$$LP_l = \begin{cases} GP_l - \text{EXPAND}(GP_{l+1}), & 0 \leq l < L \\ GP_L, & l = L \end{cases}$$

(5)

According to the equations (3) and (5), the Laplacian pyramid can be constructed.

2.3. Image Stitching and Blending Method

Assuming that there are two Dunhuang mural images called $I_A$ and $I_B$ need to be stitched and blended. The two images are combined with a determined seam, which is named after the original image $I_{\text{original}}$. In this paper, the following proposed image stitching and blending methods is used to process the original image.

Based on the above description of the Gaussian and Laplacian pyramid, the Gaussian and Laplacian pyramid of the original image $I_{\text{original}}$ can constructed. After that, the most important step is to blend the two parts of the original image in a visually pleasant way. The traditional approach is to change one image to fit another. In this paper, we intend to blend images in an adjustable way by specifying the weights of $I_A$ and $I_B$. Therefore, the final blended images $BI$ can be obtained according to the specified weights.

$$BI = \alpha \times I_A + (1-\alpha) \times I_B$$

(6)

where $\alpha$ is the weight of the image $I_A$.

According to above description, the whole steps of the proposed image stitching and blending methods for Dunhuang murals based on image pyramid can be described as follows:
- Obtaining the original image $I_{\text{original}}$ by using image $I_A$ and $I_B$.
- Generating Gaussian pyramid of the original image $I_{\text{original}}$ according to the equations (2) and (3).
- Based on the generated Gaussian pyramid, creating the Laplacian pyramid according to the equations (3) and (5).
- Blending the Laplacian pyramid. In this step, the weights of two parts of images are specified according to the equation (6).
- Reconstructing and obtaining the final blended image $BI$ based on the blended Laplacian pyramid.

3. Experimental results

In this section, we use the real Dunhuang mural images to validate the efficiency of the proposed image stitching and blending methods based on image pyramid.

In the experiments, we use two of the real mural images, $I_A$ and $I_B$, with the overlapping areas as the experimental data, the middle line of the overlapping area is used as the seam of the two images. Then the original image $I_{\text{original}}$ can be obtained, which is shown as Figure 1. Image $I_A$ and $I_B$ are the left and right part of the original image, respectively. The size of the original image is 800×1092, therefore, according to the equation (2), the level of the Gaussian pyramid is set to 8. After constructing Gaussian and Laplacian Pyramid, the final blended image results can be obtained based on the above steps described in the Section 2.

Figure 1 shows the experimental result when $\alpha$ is set to 0.5. As we can see from the figure, the seam between two parts of the original image is eliminated. From an intuitive perspective, the brightness of the experimental results is between the two parts of the original image. In addition, the final experimental results $BI$ seems high quality in a visually pleasant way. It is not only due to the proposed method works, but also because the quality of the two images $I_A$ and $I_B$ is high.

In order to evaluate the impact of the weight $\alpha$ on the final blended images, we ranges $\alpha$ from 0 to 1. Figure 2 shows the experimental results of the proposed method when the weight $\alpha$ is set to 0, 0.2, 0.4, 0.6, 0.8 and 1, respectively. As we can see from the figure, intuitively, the brightness of the image is higher and higher. In other words, the brightness is getting closer to the left part of the original image as the weigh $\alpha$ increases. It indicates that the effect of the image $I_A$ on the results is getting bigger and bigger, which matches our settings of $\alpha$. It also indicates that the proposed method can be used to blend two images in an adjustable way.

From the above experimental results, the efficiency of the proposed image stitching and blending methods for Dunhuang murals is validated. In other words, the proposed method can be used to stitch and blend two images in a seamless and adjustable way.

![Figure 1](image1.png)

**Figure 1.** The original image and the experimental result when $\alpha$ is set to 0.5.
Figure 2. Experiments results when $\alpha$ ranges from 0 to 1.

4. Conclusion
Image stitching and blending of Dunhuang murals is critical for obtaining a complete mural panorama. Although the input multiple images is high quality and high fidelity, it is also a difficult task to stitch and blend images in a visually pleasant way. Gradient domain techniques using Poisson equation is one of the approach to solve this problem. However, it consumes much time and resources. Therefore, in this paper, we proposes an image stitching and blending method based on image pyramid for addressing the above problems. Specially, Gaussian pyramid is used to down-sample the original image and construct multi-scale representations of the image. Laplacian pyramid is constructed to
calculate the difference image of the adjacent level of Gaussian pyramid. Then the blended Laplacian pyramid is used to reconstruct the final blended image by specifying the weights of different images. Experimental results have shown that the proposed method can be used to stitch and blend two images in a seamless and adjustable way. However, there are two shortcomings of our proposed method. One is how to efficiently determine the seam when only inputting multiple images. Another is how to stitch and blend multiple images rather than only two images at once.

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