An Image Stitching System using Featureless Registration and Minimal Blending

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ABSTRACT
Image stitching is useful for a variety of tasks in vision and computer graphics. This paper presents a complete system for stitching a sequence of still images with some amount of overlapping between every two successive images. There are 3 contributions in this paper. First is a featureless registration method which handles rotation and translation between the images using phase correlation even under blur and noise. The second is an efficient method of stitching of registered images. It removes the redundancy of pasting pixels in the overlapped regions between the images with the help of an empty canvas. The third contribution is a blending approach to remove the seams in the stitched output image and preserve the quality close to reality.
Keywords **– Blending, Image Stitching, Phase Correlation, Registration, Rotation, Translation**

1. INTRODUCTION
An Image mosaic is a synthetic composition generated from a sequence of images and it can be obtained by understanding geometric relationships between images. The geometric relations are coordinate transformations that relate the different image coordinate systems. By applying the appropriate transformations via a warping operation and merging the overlapping regions of warped images, it is possible to construct a single image indistinguishable from a single large image of the same object, covering the entire visible area of the scene. This merged single image is the motivation for the term *mosaic*. Various steps in mosaicing are feature extraction and registration, stitching and blending. Image registration refers to the geometric alignment of a set of images. The set may consist of two or more digital images taken of a single scene at different times, from different sensors, or from different viewpoints. The goal of registration is to establish geometric correspondence between the images so that they may be transformed, compared, and analyzed in a common reference frame. This is of practical importance in many fields, including remote sensing, medical imaging, and computer vision.

The registration method presented here uses the Fourier domain approach to match images that are translated and rotated with respect to one another. The algorithm uses the property of phase correlation which gives the translation parameters between two images if there is no other transformation between the images other than translation, by showing a distinct peak at the point of the displacement. With this as the basis, rotation is also found which is discussed in Section 2.
The next step, following registration, is image stitching. Image integration or image stitching is a process of overlaying images together on a bigger canvas. The images are placed appropriately on the bigger canvas using registration transformations to get the final mosaic. At this stage, the main concerns are in respect of the quality of the mosaic and the efficiency of the algorithm used. In this paper, an efficient method for stitching multiple images *has* been proposed. This method avoids a lot of redundancy of pasting the pixels in the overlapped region between the images and also preserves the quality of the mosaic.
Images aligned, even after undergoing geometric corrections, require further processing to eliminate distortions and discontinuities. Alignment (warping) of images may be imperfect due to registration errors resulting from incompatible model assumptions, dynamic scenes etc. Separately recorded photographs are aligned and combined to cover the entire desired region. Since the parts are recorded under different conditions, including weather, lighting, film processing and noise, they may have different gray level characteristics. This may cause seams to be apparent between two different parts. The seams can be very noticeable, and they often interfere with the perception of the details of the picture.
In this paper, an efficient method of blending multiple images called *"Minimal blending"* has been proposed. This method removes the natural seams that appear at the region of transition and does not give scope for false seams in the process, where most of the blending methods fail.

2. IMAGE REGISTRATION

2.1 TRANSLATION PARAMETERS ESTIMATION

If $f(x, y) \Leftrightarrow F(\xi,\eta)$ then

$$f(x,y)\exp[j2\pi(\xi x_0+\eta y_0)/N] \Leftrightarrow F(\xi-\xi_0,\eta-\eta_0)$$

and

$$f(x-x_0,y-y_0) \Leftrightarrow F(\xi,\eta).\exp[-j2\pi(\xi x_0+\eta y_0)/N]$$

,where the double arrow ($\Leftrightarrow$) indicates the correspondence between f (x, y) and its Fourier transform *F*. According to this property, also called as Fourier Shift Theorem, if a certain function's origin is translated by certain units, then the translation appears in the phase of the Fourier transform. i.e. if f and f' are two images that differ only by a displacement (x_0, y_0) i.e.,

$$f'(x,y)=f(x-x_0,y-y_0)$$

Then, their corresponding Fourier transforms *F1* and *F2* are related by

$$F'(\xi,\eta) = e^{-j2\pi(\xi x0+\eta y0)}*F(\xi,\eta).$$

The cross-power spectrum of two images f and f' with Fourier transforms F and F' is defined as

$$F(\xi,\eta).F'^*(\xi,\eta)/\left|F(\xi,\eta).F'^*(\xi,\eta)\right| = e^{j2\pi(\xi x_o+\eta y_o)}$$

where F'* is the complex conjugate of F', the shift theorem guarantees that the phase of the cross-power spectrum is equivalent to the phase difference between the images. By taking inverse Fourier transform of the representation in the frequency domain, we will have a function that is an impulse, that is, it is approximately zero everywhere except at the displacement that is needed to optimally register the two images. If there is no other transformation between f1 and f2 other than translation, then there is distinct peak at the point of the displacement.

As an example, for an input pair of images fig. 2.1(a) and fig. 2.1(b) with only a translation of 44 pixels along the column (x) direction, the plot of the phase correlation between the images is shown in fig. 2.1(c).

Fig. 2.1(a) *Fig. 2.1(b)*

As seen above the inverse Fourier transform of the phase-correlation is a Dirac δ-function centered at (x_0,y_0), yielding a sharp maximum. Theoretically, for exact matches (for similar images), peak value should be equal to 1; however the presence of dissimilar parts and the noise in the images reduce the peak value. It has been observed that if the peak is less than 0.03, match is unreliable.

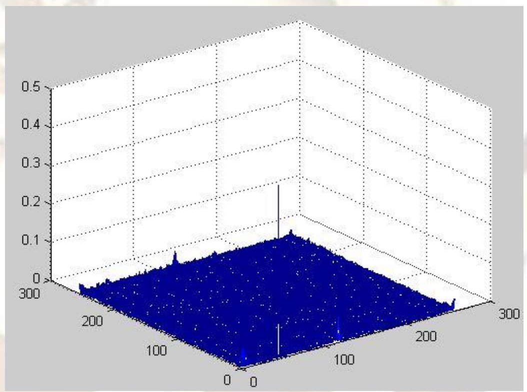


Fig. 2.1(c)

2.2 ESTIMATION OF ROTATION PARAMETERS

The discussion in the previous section tells that whenever there is pure translation present between two images, phase correlation has a maximum peak and the corresponding location gives the translation parameters (x_0, y_0). Suppose the two images I_1 and I_2 to be registered involve both translation and rotation with angle of rotation being 'θ' between them. When I_2 is rotated by θ, there will be only translation left between the images and the phase correlation with I_1 should give maximum peak. So by rotating I_2 by one degree each time and computing the correlation peak for that angle, we reach a stage where there is only translation left between the images, which are characterized by the highest peak for the phase correlation. That angle becomes the angle of rotation.

This illustrated in the following example. The marked regions in the images in fig. 2.2(a) and fig.2.2(b) are the non common regions. There is an overlap of about 25% between the images.

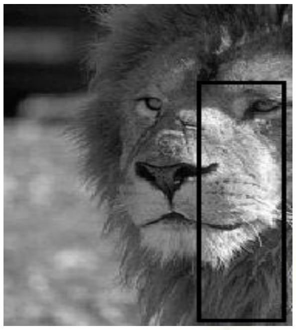


Fig. 2.2(a)

Fig. 2.2(b)

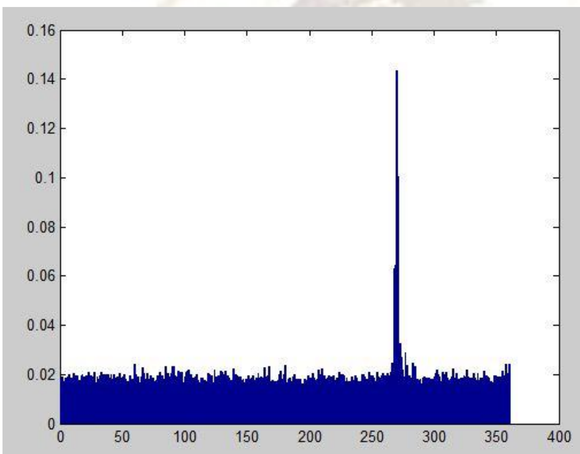


Fig. 2.2(c)

Fig.2.2(c) shows the peak values of the phase correlation for the angles 1 to 360º. From the plot of the correlation values in fig. 2.2(c), we observe that when the angle of rotation of fig.2.2 (b) is 270°, we obtain a maximum peak value of 0.1434. So, when the image in fig.2.2 (b) in rotated by 270º, there exists only translation between them. The translation is 47 pixels between them in x direction.

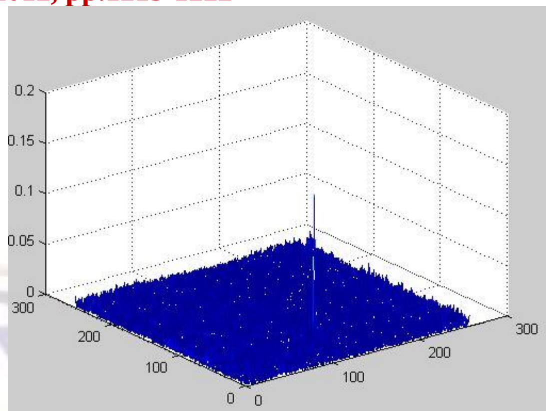


Fig. 2.2(d)

Fig. 2.2(d) shows the plot of correlation values between fig.2.2 (a) and image in the fig. 2.2(b) after rotated by 270º (where only translation exists between the 2 images). The maximum peak for the correlation occurs at (47, 59) indicating that the translation between fig. 2.2(a) and the rotated version of fig. 2.2 (b) is 47 pixels in the x direction and 59 pixels in y direction.

2.3 PROPOSED ALGORITHM

Now, we present the Algorithm for estimation of rotation and translation parameters which were discussed in the previous two sections. The algorithm uses down sampling of the images to speed up the process of registration.

<u>*Algorithm1*</u>

Input:

Two overlapping images I_1 and I_2

Output:

Registration parameters (tx, ty, θ) where tx and ty are translation in x and y directions respectively and θ is the rotation parameter. *Steps:*

1. Down sample the 2 images by 2 levels. Let the sampled images be I_1' and I_2'.

2. For i = 1: step: 360

   2.1) Rotate I_2' by i degrees. Let the rotated image be I_2'rot.
   2.2) Compute the Fourier transforms FI_1' and FI_2'rot of images I_1' and I_2 'rot respectively.
   2.3) Let Q(u,v) be the Phase correlation value of I_1' and I_2'rot, based on FI_1' and FI_2'rot.

$$Q(u,v)= \frac{FI_1'(u,v).FI_2'rot^*(u,v)}{\left| FI_1'(u,v)F'I_2'rot^*(u,v) \right|}$$

2.4) Compute the inverse Fourier transform q(x, y) of Q(u,v).
2.5) Locate the peak of q(x,y).
2.6) Store the peak value in a vector at position i.
End For.

3. Find the index of maximum peak from the values stored in the vector in step 2.6. It gives the angle of rotation. Let it be θ'.

4. Repeat steps 2.1 to 2.6 for i = θ'-step : θ'+step.

5. Find the angle of maximum peak from step 4. It becomes the angle of rotation. Let it be θ.

6. Rotate the original image I_2 by 'θ'. Let the rotated image be I_2rot.

7. Phase correlate I_1 and I_2rot. Let the result beP(u,v).

8. Compute the inverse Fourier transform p(x,y) of P(u,v).

9. Locate the position (tx, ty) of the peak of p(x, y) which become the translation parameters.

10. Output the parameters (tx, ty, θ).

The above algorithm is capable of finding rotation of any amount between the images. The maximum peak occurs only at the point where there exists pure translation between the images. The peak values do not suggest any pattern but always remain little higher near the maximum peak. A larger step size definitely improves the efficiency of the search but also has the potential for missing the peak. So the choice of the step size may depend on the type of input images.

3. IMAGE STITCHING

Image stitching is the next step following the registration. At this stage, the reference image is overlaid on the source image by pasting its pixels on a canvas at the appropriate location using the transformation parameters obtained in the registration process. In this section**,** we present a general algorithm for stitching any number of images which removes the problem of redundancy and quality degradation.

3.1 PROPOSED ALGORITHM

Algorithm2

1) Create a canvas:
The canvas is for the mosaic of all the images. We call it image canvas.

2) Make the entire canvas black.
3)For a given image I,
For each pixel in the image I,
Paste a mapped pixel on the canvas, only if the corresponding pixel is from the set of images, taking in to consideration the translational and rotational parameters.

3.2 ADVANTAGES OF THE ABOVE METHOD

This algorithm is very efficient in stitching multiple images with large overlaps. Consider a sequence of image with, let us say, 80% overlap between the successive images. If the entire image is pasted every time, then some of the pixels in the overlap region get mapped four times , thus leading to a 300% redundancy in pasting where as algorithm 2 pastes each pixel only once.

This approach not only improves the efficiency of the stitching but the same time retains the quality of the mosaic closer to that of the input images.

4. IMAGE BLENDING

The next and last step in mosaicing is *Image Blending*, which modifies the image gray levels in the vicinity of common boundary to obtain a smooth transition between images by removing the seams. Creating a blended image requires determining how pixels in an overlapping area should be presented. Performing blending in the entire overlapped region between the images is not only time consuming but also leads to poor image quality. Further, when the overlap is very large, it could lead to false seams (presented in the "Results" section). Our aim is to blend only the regions near transition. For affine geometric transformations the shapes of the overlapped regions could be quite complex. Fig. 4.1(a). shows the overlapped region for pure Translation. Fig.4.1(b) to Fig.4.1(d) include both rotation and translation.

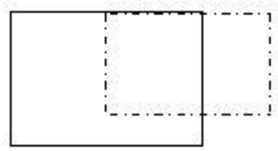


Fig 4.1(a)Rectangular

Fig.4.1(b)Triangular

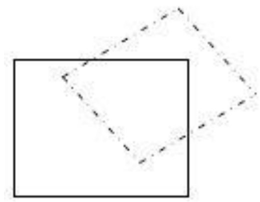


Fig.4.1(c)Quadrilateral

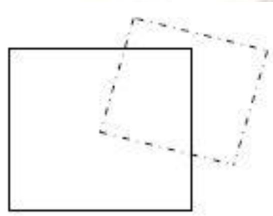


Fig.4.1(d)Polygonal

Fig 4.1 Different ways of intersection of 2 images

In a multiple image mosaicing environment, it is not easy to identify the exact region (shape) of overlap between the images but it is possible to identify the minimum rectangle which contains the region of overlap. This knowledge (information) has been used for blending along the boundaries or the regions of transition between the images.

4.1 PROPOSED ALGORITHM

Steps:<u>*Algorithm3*</u>

1) Find the direction of growth of the canvas on which the mosaic has to be created.

2) Obtain the minimum rectangle containing the entire region of overlap between the images.

3) Obtain a small region of length 'l' and breadth 'b' along the seam using the information in step 2 which depends on the region of overlap and direction of growth of the canvas.

4) Blend the region using Weighted average Blending

5. EXPERIMENTAL RESULTS

The algorithm1 for registration, algorithm2 for stitching and algorithm3 for blending as described in 2,3 and 4 sections respectively all have been implemented in MATLAB R2009a.These algorithms have been tested on different sets of images, especially real images involving large amounts of rotational and translational changes for registration and illumination and view changes for image composition.

6. RESULTS

Presenting some of the results obtained by using algorithms discussed above with step size 1.

Testsequence5.1

Registration Parameters:

translation X= 44; translation Y= 1; Rotation = 0^{o}

Mosaic:

Test sequence5.2

Registration Parameters:

translation X= 83; translation Y= 19; Rotation = 90º

Mosaic:

Test sequence 5.3

Registration Parameters:

Translation X= 65; translation Y= 35; Rotation = 2º

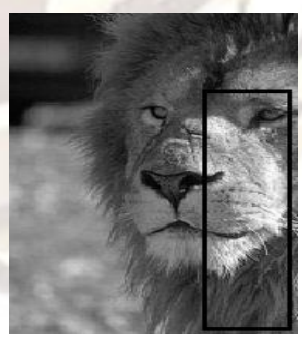
Mosaic:

The running times are presented in Table 1**.** The time taken by the Algorithm to register the images and stitch them is comparable in the case of each test sequence.

Image sequence	Time taken (in seconds)
Test sequence 5.1	12.836
Test sequence 5.2	15.732
Test sequence 5.3	17.595

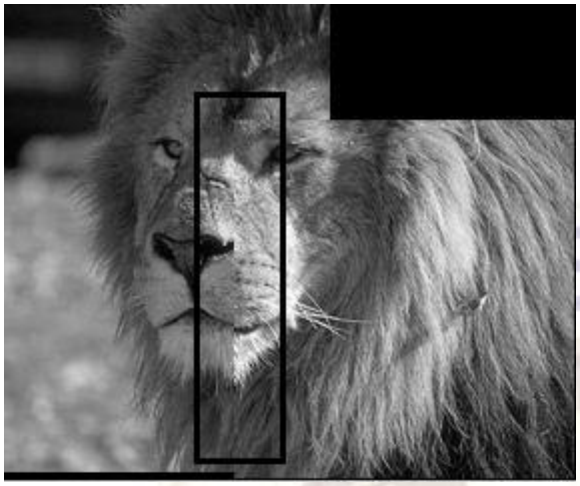
In the following, we have presented the results of some of the image compositions differentiating the mosaics with and without blending.

1) First set of images



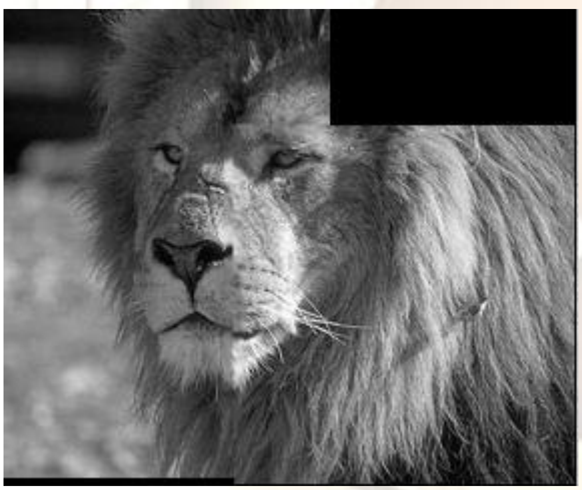
Resultant mosaic of the above images shown in 2 different cases as follows

Case 1: Without Blending



In the case of image stitching without blending, we can clearly observe the seam at the overlapping region of the two images. The resultant image for the case of stitching with blending is as shown in the below figure.

Case 2: With Algorithm 3.1 for blending



Overlap between the above set of images is 25-30%. The process involves translation and also rotation.

2) Second set of images

Overlap between the above set of images is 35-40%. The process involves translation and almost no rotation.

Case 1: Without Blending

Case 2: With Algorithm 3.1 for blending

In case 1, where blending is not done, the seams is clearly seen near the boundaries. In case 2, the seams are invisible since blending is done only along a small region along the seam.

6. CONCLUSIONS

In this paper, we have presented three algorithms for still image sequences. The first is a simple and reliable algorithm for finding rotation and transformations of planar transformations based on the phase correlation. The overall complexity is dominated by FFT. The next is a method of stitching images which overcomes redundancy in re-pasting pixels in the final mosaic. The third is a blending algorithm which uses the minimal area to be blended using weighted averaging. All these algorithms add quality and efficiency to the mosaicing process.

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