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Panorama Quality Assessment

Mohammad Javad Fadaeieslam, Mahmood Fathy, Mohsen Soryani

Abstract – *Many algorithms have been developed to create panoramic views from still images. In most of cases, the results are evaluated qualitatively. In this paper, a robust and novel method is proposed for quantitative assessment of mosaicing methods. It uses covariance descriptor to evaluate the structural similarity between panoramic view and original input images. The main advantage of this approach is its coordination with synthetic nature of the mosaicing process. Some simulations were arranged to demonstrate the effectiveness and robustness of this assessment method.*

***Keywords**: Panorama, Quality Assessment, Covariance Descriptor*

Nomenclature

SSIM	Structural SIMilarity
l	Luminance
c	Contrast
s	Structural similarity
C	Covariance descriptor
F	Feature vector
λ	Generalized eigenvalue
D_{cov}	Distance between two covariance descriptor
E	Entropy
PASS	Panorama ASSessment
MPASS	Mean PASS

I. Introduction

Creating a panoramic view from still images is an interesting field of research in computer vision. A number of robust algorithms have been proposed and several commercial software systems have been developed for this purpose [1], [2]. Most of researchers in this area evaluated their results qualitatively [2]-[4]. A robust quantitatively criterion has many applications.

It can be used to help algorithms to create better panoramic views. It will also enable consumers to select better products. Minimum squared error (MSE) and structural similarity (SSIM) are common full-reference image quality assessment methods, which are used to evaluate mosaicing results. However, the original images may have different values for one pixel due to misregistration error and exposure difference. Therefore, there is not a full reference image for comparison.

This paper presents a novel method for panoramic image evaluation. This method uses the covariance region descriptor, which is more robust against misregistration error, viewpoint and scale than the common full reference approaches. Simulation results demonstrate the effectiveness and robustness of this method.

The remainder of this paper is organized as follows: section 2 reviews the related works. Section 3 describes the pleasing panorama and investigates the existing image quality assessment methods. The proposed method is explained in section 4. Experimental results are shown in section 5 and the conclusion is given in the last section.

II. Related Works

The algorithms for generating panorama usually have two main steps in the literature: image alignment and blending. Image alignment methods can be categorized in two groups: direct (pixel-based) methods and feature based methods [1], [5], [6].

After alignment of images that participate in a panoramic view, blending is a necessary step to overcome some artefacts made by misregistration errors, exposure differences, vignetting, parallax, lens distortion and moving objects in the scene. Transition smoothing and optimal seam selection are two main approaches for this purpose.

The multi-band blending [7] is a robust transition smoothing technique that blends low frequency bands of images over a large space and high frequency bands of them over a short space.

Levin [8] stitches images in the gradient-domain to avoid exposure differences. The optimal seam selection approaches [9], [10] place a seam between two images in a region where transition from one image to another is not visible. Mills et al. [3] use both optimal seam selection and multi-band blending methods to combine two images.

To evaluate the performance of aligning step quantitatively, Brown [11] attempts to create reference panoramic view (ground truth) in two ways: virtual camera view (a software module simulating the imaging process of an actual camera) and real camera view (real images are aligned using a direct method and manual intervention for challenging situations).

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The idea of virtual camera has also been used in [12], [13] for quality assessment of mosaicing softwares. Azzari et al. [12] use the simple pixel-wise MSE method to compare generated and ground truth mosaics. SSIM which has been proposed by Wang [14] is also used in [13], [15]. The output of various panorama synthesis methods may be different in scale and viewpoint.

Therefore, these outputs must be aligned with ground truth in order to use of SSIM or MSE. This alignment may be associated with misregistration error. This error decreases the performance of these methods because they are sensitive to displacement.

Zou et al. propose a method which calculates five evaluation indices -entropy, clarity, registration error, peak signal-to-noise ratio (PSNR), SSIM- and considers a weighted sum of them as a criterion to describe the mosaicing quality [16].

They compare the mosaicing results with input images to obtain PSNR and SSIM. The weights of indices are specified by an expert. In fact, Zou et al. attempt to merge the quality of alignment and blending steps and express the final quality using one value. However, it should be considered that blending step could compensate the effects of misregistration error.

Therefore, sum of misregistration error and other parameters is not ideal.

III. Pleasing Panorama and Image Quality Assessment Methods

In order to evaluate the performance of existing image quality methods for panorama assessment, we need to define good mosaicing. In a pleasing panorama, seams between frames are not detectable by viewers and its clarity is not lower than them.

It is possible to have different values for one pixel in overlap area because of misregistration error, exposure difference, vignetting, parallax, lens distortion and moving object in the scene. In such a case, the value of this pixel must be selected in a way which doesn't seem any artefact such as blurring or cut-object in the final panoramic view. Even the selected value for this pixel may be different from the input values. In fact, panoramic view is synthesized from original images. Therefore, the pixel values aren't necessary selected from the values of original input images. With this description, pixel-wise approaches such as MSE are not good for panorama quality assessment. As mentioned in the previous section, some papers use SSIM for this purpose. The SSIM value for two image blocks **X** and **Y** is obtained from three components: luminance (*l*), contrast (*c*) and structural similarity (*s*). The SSIM and its components have been shown in Eqs. (1)-(4). In these equations, μ_x and μ_y are the means of blocks **x** and **y** respectively. σ_x and σ_y show the variances of these blocks and σ_{xy} is the covariance of **x** and **y**. C_1, C_2 and C_3 are also constants:

$$SSIM\left(x,y\right)=l\left(x,y\right)c\left(x,y\right)s\left(x,y\right) \tag{1}$$

$$l\left(x,y\right)=\frac{2\mu_x\mu_y+C_1}{\mu_x^2+\mu_y^2+C_1} \tag{2}$$

$$c\left(x,y\right)=\frac{2\sigma_x\sigma_y+C_2}{\sigma_x^2+\sigma_y^2+C_2} \tag{3}$$

$$s\left(x,y\right)=\frac{\sigma_{xy}+C_3}{\sigma_x\sigma_y+C_3} \tag{4}$$

σ_{xy} is estimated as follows:

$$\sigma_{xy}=\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i-\mu_x\right)\left(y_i-\mu_y\right) \tag{5}$$

which *N* is the number of pixels in the block. As can be seen in this relation, two blocks is compared pixel by pixel for estimation of SSIM. SSIM is categorized as a full-reference image quality assessment, which means an original image must be fully available for comparison [14]. To prepare original panoramic view, most of papers in the literature either simulate the imaging environment (virtual camera) and consider it as a reference image or compare their panoramic results with input frames. The output of different methods may be different in scale or viewpoint. Thus, an extra alignment is needed to map the mosaicing result to the original panoramic view or input images. This alignment may be associated with misregistration error:

$$\mathbf{A}=\begin{bmatrix}0 & 255 & \dots & 0\\ 0 & 255 & \dots & 0\\ \vdots & \vdots & \vdots & \vdots\\ 0 & 255 & \dots & 0\end{bmatrix},\mathbf{B}=\begin{bmatrix}255 & 0 & \dots & 255\\ 255 & 0 & \dots & 255\\ \vdots & \vdots & \vdots & \vdots\\ 255 & 0 & \dots & 255\end{bmatrix} \tag{6}$$

Study of the SSIM calculation shows that this assessment method is sensitive to misregistration error.

We illustrate this fact with an example. **A** and **B** are two 11×11 matrices which have been defined in (6). As can be seen, these matrices are stripy structures but **A** starts with 0 and **B** with 255.The structural similarity between these two matrices is:

$$\mathrm{SSIM}\left(\mathbf{A},\mathbf{B}\right)=-0.6884 \tag{7}$$

As can be seen in this relation, despite the similarity between these two matrices, SSIM shows them contrasting.

IV. Covariance Based Panorama Quality Assessment

As mentioned in the previous section, SSIM consists of three components: luminance, contrast, and structural similarity. In the proposed algorithm, we replace the contrasting and structural similarity components with a component based on covariance descriptor [17], [18]. The covariance descriptor is a region descriptor which is more robust against scale, viewpoint and misregistration error.

Using this descriptor, we are able to fuse different types of low-level features into a small 2D-matrix efficiently. To extract this feature, each pixel of a window is converted to an six-dimensional vector $F(x,y)$:

$$F(x,y) = \left[x, y, |I_x|, |I_y|, |I_{xx}|, |I_{yy}| \right] \tag{8}$$

In this vector, *x* and *y* represent the location of pixel. **I** is the pixel intensity. I_x, I_{xx}, I_y and I_{yy} are the first and second order derivatives of intensity in *x* and *y* directions.

The covariance of these vectors (referred to as *C*) composes a 6×6 matrix to characterize the window [17]. The covariance matrix space is not a vector space.

Therefore, methods based on arithmetic differences can not specify the difference between two covariance matrices.

In this paper, the distance metric that is proposed by Foerstner and Moonen [19] (Eq. (9)) is used to calculate the dissimilarity between two covariance matrices (C_1 and C_2). In this equation, $\{\lambda_i(C_1,C_2)\}_{i=1..n}$ are the generalized eigenvalues of C_1 and C_2:

$$D_{cov}(C_1,C_2) = \sqrt{\sum_{i=1}^{n} ln^2 \lambda_i(C_1,C_2)} \tag{9}$$

D_{cov} is a metric [19]. Consequently, it has the following properties:

$$\begin{aligned} &D_{cov}(C_1,C_2) \geq 0 \\ &D_{cov}(C_1,C_2) = 0 \Leftrightarrow C_1 = C_2 \\ &D_{cov}(C_1,C_2) = D_{cov}(C_2,C_1) \\ &D_{cov}(C_1,C_2) \leq D_{cov}(C_1,C_3) + D_{cov}(C_3,C_2) \end{aligned} \tag{10}$$

According to these properties, our proposed assessment method for contrasting-structural evaluation of block *i* (p_i) from panoramic view which is extracted from two initial input images (**x** and **y**) is:

$$E_{xy_i} = max\left(Entropy(\mathrm{x}_i), Entropy(\mathrm{y}_i)\right)/8 \tag{11}$$

$$\begin{aligned} &PASS_i(x_i, y_i, p_i) = \\ &= \frac{D_{cov}(x_i, y_i) + 1}{D_{cov}(x_i, p_i) + D_{cov}(y_i, p_i) + 1} E_{xy_i} \end{aligned} \tag{12}$$

In (12), the maximum entropy of input blocks is multiplied. This factor gives more weights to the blocks with more information. The range of pixel values is from 0 to 255. As a result, the maximum value of E_{xy_i} will be 8.

The value of our proposed method, PASS, varies between 0 and 1. If x_i or y_i is identical to p_i, then $PASS_i$ will give the value of 1.

If two input blocks and panoramic view are different, then $D_{cov}(x_i, p_i) + D_{cov}(y_i, p_i) \geq D_{cov}(x_i, y_i)$ and $PASS_i \leq 1$. In this situation, synthesis of p_i with minimum distance from x_i and y_i maximizes the value of $PASS_i$. The contrasting-structural quality of panoramic image is obtained from the following equation:

$$\begin{aligned} MPASS &= \frac{\frac{1}{M}\sum_{i=1}^{M} PASS_i(x_i, y_i, p_i)}{\frac{1}{M}\sum_{i=1}^{M} E_{xy_i}} = \\ &= \frac{\sum_{i=1}^{M} PASS_i(x_i, y_i, p_i)}{\sum_{i=1}^{M} E_{xy_i}} \end{aligned} \tag{13}$$

In this equation, *M* is the number of blocks in overlap area. The value of MPASS varies between 0 and 1. In the experimental results section, the performance of the proposed scheme (referred to as PASS) is compared with SSIM.

V. Experimental Results

There is no database in the literature for evaluation of mosaicing methods. Thus, we have taken the images of LIVE database [20] and have simulated some errors which are occurred in the process of panorama creation to evaluate the proposed method. The main two errors which are considered in this paper are blur and misregistration.

The proposed quality assessment (Eq. (12)) is independent of luminance variations. Thus, we compare it with contrasting and structural parts of SSIM. In other words, $\mathrm{SSIM}_{cs}(x,y) = c(x,y)s(x,y)$ is compared with (12) (To create a comprehensive criterion, the *l* part of SSIM must be multiplied by (12)).

The first experiment evaluates the effect of blur on the proposed method (PASS) and SSIM_{cs}. Three Gaussian blur kernels (of size 5×5) with standard deviations σ =0.65, 0.75, 0.85 are applied to the database images.

The difference between each original image and its blurred one is estimated with SSIM_{cs} and PASS. The results are shown in Fig. 1. The horizontal axes shows the image number. There are 29 images in this database. As can be seen, the distance between two lines for all images is nearly constant for the proposed method (red lines).

In other word, the similarity decreased uniformly when input images blurred with constant σ.

Another experiment is also arranged to study the effect of misregistration error. For this purpose, three images are constructed from an original image in the database namely **X**, **Y** and **P**. **X** is the original image which is shifted one pixel to the left and up. **Y** is also obtained by shifting one pixel to the right and down. These two constructed images are considered as the input of mosaicing module and **P** is also considered as the output of it.

In the first test, **P** is set to the original image and in the second one, the Gaussian blur kernel with standard deviation σ =0.65 are applied. The results are shown in Fig. 2. As can be seen in this figure, the proposed method is more robust against misregistration error and more sensitive to blur in comparison to $SSIM_{cs}$.

In $SSIM_{cs}$ scheme (blue lines), the similarity between panoramic view and input images increased when **P** is blurred.

In order to evaluate $SSIM_{cs}$, we have two values for each pixel because of two input images. Similar to [16], mean of them is selected for these experiments.

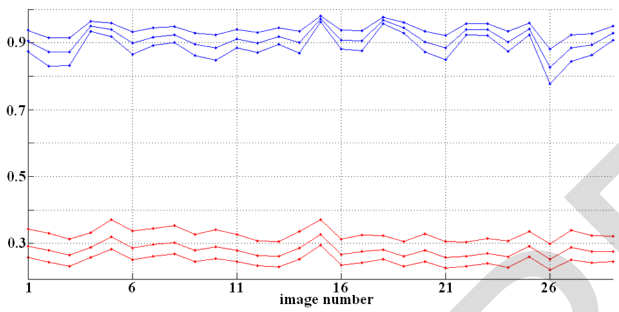

Fig. 1. The effect of blur on two quality assessment approaches; red lines show PASS results and blue lines show $SSIM_{cs}$ results. There is only one input image in (12). Thus, we set $D_{cov}(y_i, p_i) = D_{cov}(y_i, x_i) = 0$

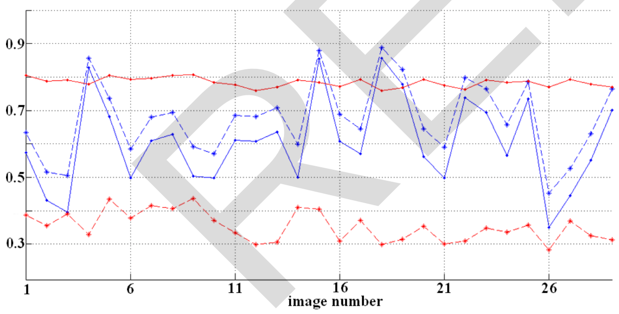

Fig. 2. The effects of misregistration error and blur on SSIM and the proposed method; red lines show PASS results and blue lines show $SSIM_{cs}$ results. The results of the first test (misregistration error) are shown with solid lines. Dashed lines are regarding to the second test (misregistration and blur)

VI. Conclusion

Many algorithms have been developed to create panoramic views from still images. Most of these algorithms evaluated their results qualitatively.

In this paper, a robust and novel approach is proposed for quantitative assessment of mosaicing methods. It uses covariance descriptor to evaluate the structural similarity between panoramic view and two original input images.

The main advantage of this assessment method is its coordination with synthetic nature of the mosaicing process. In addition, it is more robust against misregistration error, viewpoint and scale than the common full reference methods. The input images may have different values for one pixel due to misregistration error, viewpoint and exposure difference. On the other hand, the results of mosaicing methods may be different in scale and viewpoint.

Thus, the pixel-wise schemes such as MSE or assessment methods which are sensitive to misregistration error (such as SSIM) are not appropriate for panorama assessment. To evaluate the proposed method, some simulations were arranged because there is no suitable database for this purpose. All of these simulations have shown that the proposed method is robust and effective for panorama quality assessment.

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