COMPENSATION OF LOCAL DEFECTS IN IMAGES TAKEN BY THE TECHNIQUE OF TRIPLE COLOR PHOTOGRAPHY[1]

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The problems of detection and compensation of local defects in images taken by the technique of triple color photography are under consideration. The automated procedures for detecting and compensating local defects are developed, implemented in the software tool, and applied to reconstruction of the collection of color photographs taken by S.M. Prokudin-Gorsky at the beginning of the XX century.

Introduction

In this paper the problems of digital image processing concerned with the reconstruction of a set of color photographs named "The Collection of the Splendors of Russia in Natural Colors", created by S.M. Prokudin-Gorsky during 1905-1916 years. The particular implementation of the technique of triple colour photography used by Prokudin-Gorsky has been developed by A. Miethe at the beginning of the 20th century. A camera registered on a single glass plate three separate black and white frames taken through the blue, green and red filters. The collection includes 1902 triple glass negatives of size 9 by 24 cm.
The glass negatives are preserved at the Library of Congress, USA. Glass negatives have a lot of defects caused by different factors. In 2000 all triple-frame glass negatives were scanned by JJT Company in 16-bit grayscale with a resolution in excess of 1000 dpi. As a result, a set of image files, each of a size about 70 Mb, was obtained. All of the images are available on line. After the negatives has been scanned color registration of all 1902 triplet negative images was done in 2001 at the Russian Academy of Science by V. Minachin and Yu. Davidov [3]. The results are presented in [4].

In this work, the problems concerned to the development of a technology for automated detecting and compensating of local defects in digital images of the Prokudin-Gorsky's collection are investigated.

Features of Triple Glass Negative Images

The features of the triple glass negative images are conditioned by the technique of triple photography and by appearance of negative glass defects. (1) Defects detection and compensation are performed after color registration and correction of perspective distortions caused by the technique of photography. (2) Three frames of the same scene are available. Information in image color components outside of defect regions is rather strongly correlated (similarly to the frames of movies [2, 6]) and is weakly correlated in the defect regions. (3) Single defect usually appears only in one negative of the triplet. But the situation, when different defects in different frames of the triplet take the same spatial position, is possible. (4) Because of the original glass negatives are not available, one can only analyze the appearance of the defect in digital image. (5) High resolution and large image size. (6) A great number of defects (hundreds and even thousands in particular images) and variety of their appearance.

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For developing procedures for detection and compensation of defects one should take into account triple negative image features listed above and peculiarities of defect appearance [5].

Problem Formulation

The objects of investigation are triplets of grayscale images of about 3600x3300 pixels obtained by scanning triple glass negatives. The images of a triplet are corresponding to red, green, and blue components of the photograph. Digital images have a lot of artifacts reflecting different defects of negatives caused by various factors [4].

For reconstruction of the collection it is necessary to localize and remove artifacts in digital images preserving historical authenticity of image content.

The huge amount of graphic material and the great number of defects in glass negatives lead to the development of automated procedures for local defects detection and compensation, meeting the requirement of authenticity and reducing the volume of manual operations in reconstruction.

In [2, 6] simple models of film defects of different types are suggested. Generalizing these models we will formulate the tasks of defect detection and compensation.

The task of defect detection is formulated as follows. Let the continuous real functions $u^k = u^k(x,y)$, $\mathrm{x} = (x,y)^T$, $\mathrm{x} \in X$, $u^k : X \to R$, $k = 0,1,2$ defined in some domain $X \subset R^2$ describe the grayscale relief in a defectless image triple corresponding to R, G, and B channels. Let the functions $v_{ij}^k = v_{ij}^k(x,y)$, $v_{ij}^k : X \to R$, $i = 1,2...,N_j$, $j = 1,2,...J$, $v_{ij}^k \in R$ describe the relief of the defect D_{ij}^k, where i is the defect number and j is the defect class number. Let $v_{ij}^k \neq 0$ only at points $\mathrm{x} \in D_{ij}^k$, $D_{ij}^k \subset X$. Let the mapping $\varphi_j : X \times R \to \{0,1\}$ describes the detector of defects of a class *j*. In an ideal case $\varphi_j(\mathrm{x}, u^k + \sum_{i,j} v_{ij}^k) = 1$ only for $\mathrm{x} \in D_{ij}^k$. For detection of defect regions it is necessary to find a set of points $\{\mathrm{x}\}^k$, where $\varphi_j = 1$; $j = 1,2,...J$. In an ideal case $\{\mathrm{x}\}^k = \bigcup_{i,j} D_{ij}^k$. The result of the detection depends on defect appearance in an image and on the image properties in the neighborhood of the defect region. The task of image correction is formulated as the task of finding functions $w_{ij}^k = w_{ij}^k(x,y)$ satisfying the conditions $\varphi_j(\mathrm{x}, u^k + \sum_{i,j} v_{ij}^k + \sum_{i,j} w_{ij}^k) = 0$.

Taking into account some kind of content similarity in R,G,B channels, the following conditions are imposed on functions w_{ij}^k: $\iint_{D_{ij}^k} \left| \alpha_{ij}^l u^l - (u^k + v_{ij}^k + w_{ij}^k) \right| dxdy < \delta$, where $\alpha_{ij}^l > 0$ is the coefficient, $\delta > 0$ is the given number, $l = 0,1,2$; $l \neq k$.

Defect Detection

A lot of publications on techniques for detecting and retouching of images obtained by scanning of old photographs and films can be found [2, 6, 7]. Taking into account the specificity of the triple colour photography technique, the following necessary condition for conсidering an object in the image as a defect can be formulated: if an object in the colour image is a defect, it can be found only in one component of the tripplet. To reduce the error probability, the following rule is formulated. Once defect regions in different color components may be located at the same spatial position and may overlap in the registered colour image, the suspicious region should be considered as a defect only if it is located in the same place in no more than two images of the triplet. In other cases it will be considered as a detail of a scene.

On the base of the detection task formulation, one of the possible detecting functions for homogeneous image fragments can be defined as follows.

Let $\bar{u}^k$ be a mean value of the function u^k in some domain $F^k \subset X$, $u_m \leq u^k(\mathrm{x}) \leq u_M$ for $\mathrm{x} \in F$, where u_m и u_M are minimum and maximum of u^k in *F*. The simple detecting function can be constructed as follows:

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$$\varphi_j = \begin{Bmatrix} 1, \; u(x) > u_M^k, \, u(x) < u_m^k; \\ 0, \; u_m^k \le u(x) \le u_M^k. \end{Bmatrix}$$

The mask of the defect region $\mu_{ij}^k : X \to R$ is defined as:

$$\mu_{ij}^k(\mathrm{x}) = \begin{Bmatrix} 1 - u^k(\mathrm{x}) / u_M^k, \varphi = 1; \\ 0, \qquad \varphi = 0. \end{Bmatrix}$$

The combined procedure for detection of local defects using subsequently a set of algorithms is developed. It can be applyed for localizing the following groups of defects: emulsion losses, pollution, emulsion degrading, artifacts conditioned by moving objects. A set of implemented techniques can be divided in two groups. The first group includes those, which are analyzing images of a triplet separately: the technique based on combined morphological opening and closure operations [1], the gradient-based technique, the threshold-based detector. Techniques from a second group are analyzing all images of a triplet simultaneously, for example, the technique based on calculating pairwise differences of grayscale values in R, G, and B components in the same spatial position.

The developed procedure includes the following steps. (1) Segmenting image color components into a set of relatively homogeneous large regions (for example, sky, water surface, buildings, etc.). (2) For each of these regions in triple images a set of algorithms is applied sequentially for detecting defects of different groups. As a result, a set of mask triplets marking suspicious regions is obtained. (3) Composing resulting mask triplet using the formulated above rule. (4) Coordinates of found defect regions are recorded in the database for subsequent verification by experts. During verification, the false defect regions are removed from the masks.

Compensation

Several commercial programs equipped with toolboxes for image registration, correction, and retouching are available now (for example, Adobe Photoshop, Correl Draw, Paintshop Pro, and some others). However, retouching triple images from the particular collection by standard tools meets some difficulties conditioned by (1) the great number of images; (2) the variety of defect appearance; (3) standard tools do not use the peculiarities of the triple color images.

Two different classes of correcting techniques should be outlined. Techniques of the first class should be applied in case when restoration of lost fragments in one of the triplet images is possible using information from correspondent regions in other images of the triplet. Methods of the second class (image inpainting methods) are necessary in cases when the image fragments are lost in all of the images composing a triplet. For the first case, from the formulation of the compensation task, the following correcting function can be derived:

$$w_{ij}^k = \mu_{ij}^k(\alpha_{ij}^l u^l + \alpha_{ij}^m u^m)/2 + (1 - \mu_{ij}^k)(u^k + v_{ij}^k),$$

where $\mu_{ij}^k : X \to R$ is the masking function for the defect of number i from the class j in the channel k. Parameters α_{ij} are calculated from the condition of equality of the mean grayscale values inside the defect regions after correction to the mean grayscale values in the neighborhoods of these regions.

The following procedure for correction of local defects is developed. (1) The first object corresponding to defect region is found in the mask image obtained for one of the color components. (2) The mean grayscale value in the neighborhood of the defect region in the color component image is calculated. (3) Using the mask, the corresponding fragments in other color components are found. Grayscale values of reconstructed pixels in the damaged fragment are calculated taking into account the mean intensity value in the neighboring region. (4) The object corresponding to the restored region is removed from the mask. (5) The steps 1-4 are repeated till all of the detected defect regions are restored. (6) The next mask is taken, and steps 1-5 are repeated.

Results

In Fig. 2 the results of applying the developed procedures for detecting and compensating of local defects, to the color registered image fragment are shown in Fig. 1. A lot of defects can be seen in the negative triplet images including emulsion losses, emulsion degrading, and pollution. The presence of an object with

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texture (a tower) complicates the process of localization.

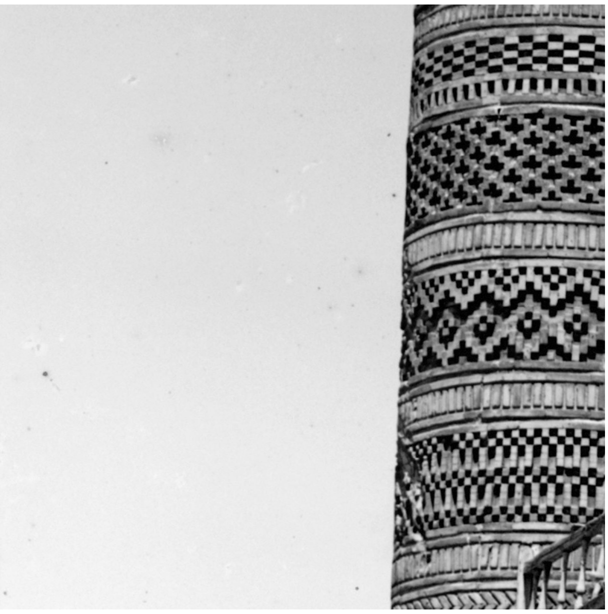

Fig. 1. Fragment of size 795x795 pixels of an image after color registration.

The developed automated procedure, implementing a few simple algorithms working subsequently, was applied for local defect detection. In rather homogeneous image region (the sky in the left part of the fragment) the gradient-based technique was applied separately in R, G, and B channels. For the refinement of defects boundaries, pixel-by-pixel classification in sliding window of size 200x200 pixels was used. In the textured region a technique based on evaluating pairwise differences of grayscale values in R, G, and B components in the same spatial position, was applied. After processing of mask triplets, generated by the applied techniques, in order to exclude false defect regions, the set of the resulting mask triplets was obtained. In red image component 98 defects were found, in green – 107, and in blue - 62. After detection, the developed correcting procedure was performed using the set of resulting masks. The output image is shown in Fig. 2.

Conclusion

The efficient automated procedures for detecting and compensating local defects in the images created by the technique of triple color photography are developed. The procedures are implemented in the software tool and are applied to reconstruction of the collection of color photographs taken by S.M. Prokudin-Gorsky at the beginning of the XX century.

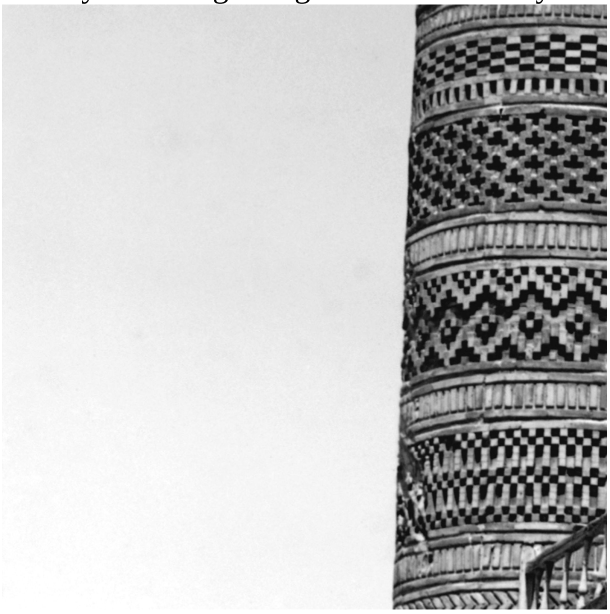

Fig. 1. Corrected image fragment shown in Fig.1.

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