A TECHNIQUE FOR RESTORATION OF TRIPLE COLOR IMAGES

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The problems related to the restoration of digital images reconstructed in color from triple black and white negatives are considered. The techniques for defect detection and compensation are proposed, implemented in software tools and tested.

INTRODUCTION

In this paper, the problems related to the restoration of digital images reconstructed in color from triple black and white negatives taken by S.M. Prokudin-Gorsky in 1905-1916, are considered. 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. The 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 glass negatives of size 9 by 24 cm. The glass negatives are preserved at the Library of Congress, USA[1]. The complete collection was for the first time reconstcructed in color in high resolution by V. Minachin and his team in 2003[2]. An optimal perspective transformation of the blue and red frames with respect to green, providing the total matching error on the sub-pixel level, was found.
However these images are scanned from the material which is over 100 years old and the original glass plates usually contain defects of different kind. The features of the images are conditioned by the technique of triple photography and by appearance of negative glass defects. (1) Defects detection and compensation will be performed after color registration and correction of perspective distortions. (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[5,8]) and is weakly correlated in the defect regions. (3) Single defect usually appears only in one frame of the triplet. But the situation when different defects in different frames 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 a variety of their appearance.
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 are leadind 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.

RELATED WORKS

First several photographs has been reconstructed at Kodak Labs for the book by R. Allshouse "Photographs for the Tsar" that appeared in 1980[4]. After the negatives has been scanned, different specialists independently started their research in this field. Some of this works should be outlined.
During 2000-2001 about 180 photographs were reconstructed and retouched by the professional photographer W. Frankhauser using Adobe Photoshop tools. In spite of great volume of manual operations this work is valuable because it was done by the professional photographer and the results may be used in the future works. Another research has been conducted at Princeton University by B.A. Arcas. As a result, a fully automated algorithm for color registration has been developed and applied to the whole collection[1]. The technique applies local shift and rotation transformations minimizing the registration error in several image fragments. Compensation of defects caused by the moving objects is based on shift field evaluating. Unfortunately the algorithm does not provide the proper accuracy for static objects in 15% of images. One can find a number of WEB resources containing fragments of the collection and the results of research, but they provide only information related to particular topics.
A set of frames associated with one negative, the huge amount of graphic material, and the great number of defects are common for this research and for works concerned with restoration of old movies. In spite of difference in the types of images, the techniques for movie restoration can be applied for localizing and compensation defects in the images of the particular collection.
A technique for detecting deteriorations appeared as dark or bright spots with rather smooth boundaries, was proposed by Joyeux et.al.[5]. It is based on combining morphological opening and closure operations with

structural elements of two types (one of them is flat with zero elements, and another one is non-flat). The use of structural elements of different sizes permits to take into account the slope of image gradients.
In works[6,7] methods for localizing and compensating sparkles, pollution and clutters appeared as an additive white noise in films and TV images were considered. For detecting sparkles and spots, heuristic and model-based approaches were used. The most efficient technique is based on thresholding forward and backward pixel differences in different frames. For defects correction a median filter and 3D autoregressive method were applied. The autoregressive technique appeared to be highly sensitive to defect size and computationally expensive. These factors decrease the efficiency of the method. For suppressing noise the Wiener filter was applied. Within the program "AURORA"[8], methods for searching and removing spots, jitter, and noise in movies were studied. Author provides comparison of efficiency of several spot detectors for different types of image sequences. All of the tested detectors demonstrated the best results for low contrast and low dynamic image sequences. Low stability of tested detectors was caused by the lack of automated methods for choosing optimal parameter values. Fixed parameter values could not provide good results for images of all types. The author presented modified spot detectors with post-processing based on rank statistics. For spot removing, he proposed the interpolation technique with controlled pixel data transferring from adjacent frames. Some techniques for specific film defects can be found in works[9-11].
The brief review of the related works has shown that the problem of local defects compensation was solved only in part for Prokudin-Gorsky collection. In this work we will try to develop restoration tools for collections of images obtained in the technique of triple color photography. Some ideas and techniques, for example, data transferring from adjacent frames, developed for movie restoration tasks, can be implemented in the techniques for restoring triple images.

IMAGE RESTORATION

In works[7,8] models of film defects of different types are suggested. Using analogous models, we will formulate the tasks of defect detection and compensation.

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 images and on image properties in the neighborhood of the defect region.
Taking into account the specificity of the triple colour photography technique, the following necessary condition for conciderincluding an object in the image as a defect can be formulated: if an object in the color image is classified as a defect, it can be found only in one component of the tripplet. On the base of the detection task formulation, one of the possible detecting functions for homogeneous image fragments can be defined as follows. Let $\overline{u}^k$ - be a mean value of the function $u^k(\mathrm{x})$ in some domain $F^k \subset X$, $u_m \le u^k(\mathrm{x}) \le u_M$ 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 in such a way:

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

The mask of the defect region $\mu_{ij}^k : X \to R$ is defined as $\mu_{ij}^k(\mathrm{x}) = \begin{Bmatrix} 1, & \varphi_j = 1; \\ 0, & \varphi_j = 0. \end{Bmatrix}$.

The combined procedure for detection of local defects using subsequently a set of detectors, is developed. It can be applied for localizing the following groups of defects: emulsion losses, pollution, emulsion degrading, artifacts conditioned by moving objects, scratches, and defragmentation. A set of implemented detectors includes: (a) threshold-based detector (1) with parameters calculated from the mean and dispersion in sliding window; (b) detector based on combined morphological opening and closure operations[5]; (c) gradient-based detector with Otsu thresholding algorithm; (d) the threshold-based detector with fixed threshold values for detecting losses of emulsion and non-transparent pollution; (e) detector 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, 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.

The detectors listed above are implemented in the specialized software tool and were tested on a set of test images and real triple negative images taken from the collection. Test images are composed using digital color photographs with different content. The models of defects typical for Prokudin-Gorsky collection were synthesized by blurring black and white circles of diameters from 3 up to 17 pixels. From 40 to 150 artificial defects were embedded into R, G, and B image components. Parameters of detectors were chosen versus defect size and statistical characteristics of image regions. The goal was to maximize sensitivity and to minimize false defects number. At the average the percentage of detected defects reached 95%. The number of false defects strongly depends on image contents and increasing for images with textural regions. The most efficient detectors appeared threshold-based detector with parameters calculated from statistical characteristics in sliding window, detector based on combined morphological operations, and gradient-based detector with Otsu thresholding algorithm. Testing has shown that none of the detectors provides 100% efficiency and it is necessary to use several detectors. The steps of defects detecting are illustrated in Fig 1.

Several commercial programs equipped with toolboxes for image registration, correction, and retouching are available now (for example, Adobe Photoshop). 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. Here, the inpainting procedure using correlation of content in different color components is proposed. Correlation between different triple frames is conditioned by the spectral characteristics of filters implemented in camera. Using the model of photographic process[13] and filters characteristics[12] it is shown that the grayscale pixel values at the same spatial position in different frames of the triple meet the relationship $u^k(x,y) = \alpha^l(x,y,\lambda)u^l(x,y)$, where $\alpha^l(x,y,\lambda)$ is the factor depending on wavelength λ of the exposing light. If the grayscale level in the neighborhood of point (x,y) is changing slowly, the factor α^l may be considered as a constant. On the base of this assumption one can obtain inpainting algorithm using information from the other frames of the triplet. The task of image correction may be formulated as the task of finding functions $w_{ij}^k = w_{ij}^k(x,y)$ satisfying the conditions (detectors should not register retouched regions) $\varphi_j(\mathrm{x}, u^k + \sum_{i,j} v_{ij}^k + \sum_{i,j} w_{ij}^k) = 0$. Taking into account some kind of content similarity in R,G, and B channels, the following conditions are imposed on functions w_{ij}^k:

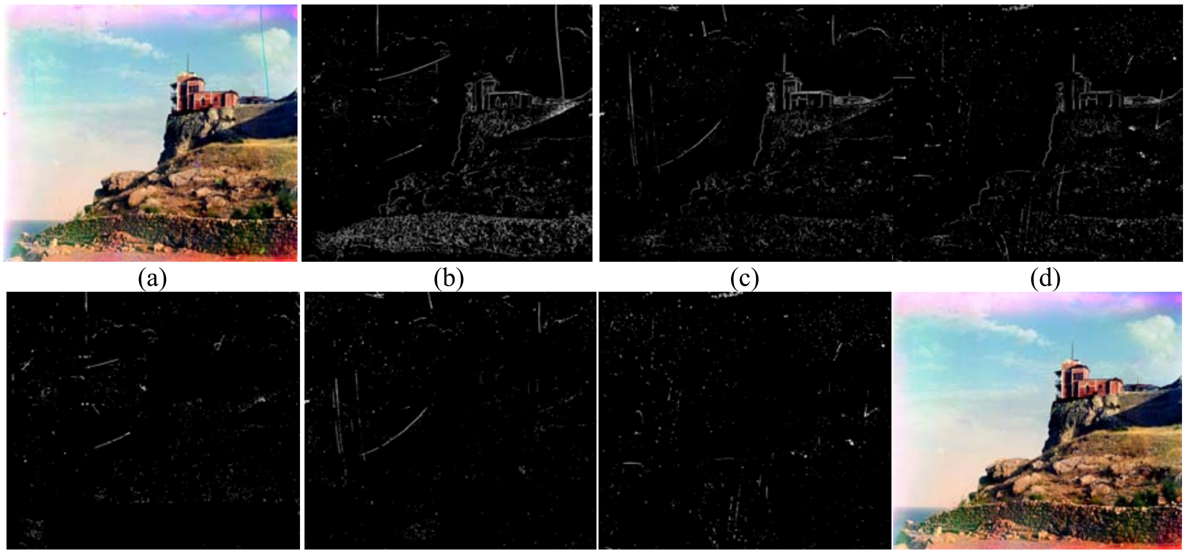
$$\iint_{D_{ij}^k} \left| \alpha_{ij}^l u^l - (u^k + v_{ij}^k + w_{ij}^k) \right| dxdy \le \delta, \tag{2}$$

where α_{ij}^l - is the coefficient, $\delta \ge 0$ – is the prescribed value of the integral error, l=0,1,2; k=0,1,2, $l \ne k$. Setting $\delta = 0$ in (2), the following correcting function can be obtained: $w_{ij}^k = \mu_{ij}^k(\alpha_{ij}^l u^l + \alpha_{ij}^m u^m)/2 + (1-\mu_{ij}^k)(u^k + v_{ij}^k)$, where $\mu_{ij}^k : X \to R$ is the masking function for defect 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 correcting 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 processed. (6) The next mask is taken, and steps 1-5 are repeated. The steps of restoration procedure are illustrated in Fig. 1.

CONCLUSIONS

The problems concerned with reconstruction of historic images taken in 1900's by the technique of triple color photography are considered and solutions are proposed. The techniques for defect detection and compensation are proposed, implemented in software tools and tested. The developed techniques will be useful for restoration of other collections of triple color photographs.



(a) (b) (c) (d)

(e) (f) (g) (h)

Fig. 1. Defects detection: (a) - registered 3365 by 2973 color image; (b) – (d) - suspicious regions in R, G, and B components; (e) – (g) – binary defect masks; (h) - restored image

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