RECONSTRUCTION OF HISTORIC IMAGES TAKEN IN 1900'S BY THE TECHNIQUE OF TRIPLE COLOR PHOTOGRAPHY: PROBLEMS AND SUGGESTED SOLUTIONS

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The problems related to the restoration of digital images reconstructed in color from triple black and white negatives taken in 1900's by the technique of triple color photography are considered and solutions are proposed. Classification of defects in images acquired by scanning triple glass negatives is developed. Automatic algorithms for detecting, identifying, and correcting defects in registered color images are proposed and discussed.

Introduction

In this paper we consider 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 S.M. Prokudin-Gorsky (1863-1944), an early 20th century Russian photographer and researcher, has created "The Collection of the Splendours of Russia in Natural Colours" - the unique set of colour photographs of the Russian Empire on the eve of the October Revolution of 1917. 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. In 2000 all triple-frame glass negatives were scanned in 16-bit grayscale with a resolution in excess of 1000 dpi. All of the images are available online [1].

This is the first example of a collection of historic triple color photographs which was made available for reconstruction in color. The complete collection (1902 images) was for the first time reconstcructed in color in high resolution by V. Minachin and his team in 2003 [2]. Levenberg-Marquardt numerical algorithm [5] was used for finding the optimal perspective transformation of the "blue" and "red" frames with respect to the "green" in such a way as to minimize the total matching error on the sub-pixel level. Before that no one, including the photographer, has ever seen the complete set of images in color – the hard copy archival items present triple black and white images. Only a smaller part of the collection has been displayed in the years of its creation – mostly by triple projection or printing, none of which had been able to exhibit the quality of color detail retained in the triple glass plate. This irony of triple color photography (i.e. that the authors had never seen their complete collections in color) probably contributed to its eventual replacement by other techniques (e.g. autochromes) which produced color images directly (instead of a set of three black and white frames).

Prokudin-Gorsky collection was the first triple color archive which has been fully reconstructed in color [3,4]. Others will probably follow. In our days it is both necessary and possible that in order to be usable a triple color collection should include a set of digital color reconstructions as its essential part. Its purpose goes beyond the customary digital backup of the hard copy items. Indeed, the color reconstructions is what the end users of the collection will most often go to. We believe it important that in order to qualify for the position of the primary usable set such reconstructions should observe a number of conditions.

1. The color reconstructions should be produced from the scans of the highest possible

quality. The resolution of the scans must be selected in such a way that every image detail visible on the triple black and white carrier is visible on the scan.

2. The “first line” color registrations should be made with the pixel accuracy over static objects.

3. No retouching or cropping of the color images are desirable at this stage.

Therefore, the “minimal” triple color archive should consist of (a) triple hard copy originals and any accompanying historic material; (b) a set of “first line” color reconstructions satisfying conditions (1) - (3).

The experience of reconstructing Prokudin-Gorsky collection has shown that the color reconstructions created [2] according to these principles not only preserve the complete archival information but also in most cases provide color images which are quite usable and in fact attractive for the exhibition purposes.

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. We strongly advocate the “non-retouching” policy for the “first line” archival set of registered color images. If this principle is observed this set of digital reconstructions will contain defects which, in most cases, are inherited from one of the three frames of triple black and white negatives.

The question which we start to investigate in this paper is whether the properties of triple color material does in principle allow for the production of the “second line” set of partially corrected digital reconstructions which will have some of these defects removed on the basis of information contained in two other frames of the image.

More precisely we address the following research tasks. (1) Describe the class of defects which can be automatically identified in the registered color image and develop reliability criteria for the detection process. (2) Analyze and describe the subclass of such defects which can be reliably corrected without adding arbitrary changes to the image that cannot be justified by information containing in the original triple black and white material.

This article contains partial results related to both issues.

2. Defects of Historic Glass Negatives: Features, Classification, Description

For the purpose of obtaining feature sets and developing techniques for successful detection and compensation of defects, their etiology, localization, and appearance in images should be taken into consideration [10, 11]. We start by providing description and preliminary classification of defects appearing in the Prokudin-Gorsly negatives. Archival practice usually classifies negative defects according to the following features.

I. Localization. Defects may be located on the base, on the emulsion, mixed (i.e. the defect affects both the base and the emulsion).

II. Cause. Mechanical damage (caused from either outside or inside), exogenous pollution (fingerprints, dust, mud, dye, paper or glue fragments etc.); endogenous physical and/or chemical processes, biological damage (fungus, etc.); optical artifacts registered by the emulsion (parasitic exposure, specks of lens internal surfaces, plate-holders in cassettes, mixed).

III. Appearance. Negative defects may differ by: (1) form (e.g. scratches or cracks differ from spots); (2) structure; (3) size (in relation to the frame area); (4) gray scale intensity level (or by optical density); (5) intensity profile; (6) transparency: (a) non-transparent, (b) transparent, (c) mixed (with variable and/or peripheral transparency); (7) predictability of damaged region (using information from the neighborhood): (a) smooth gradients, predictable content, (b) many small details, complicated gradients; (c) different degree of duplication of the same fragment in other color components. For the purpose of localizing defects, the most important features are form, size, structure, and intensity profile.

Since our research was conducted on the scanned digital images and we did not examine the glass negatives themselves, our understanding of the causes, nature, and initiation mechanisms of the specific defects is based on prior experience and specific characteristics visible on the scans. Some of the possible factors leading to defect formation are listed below.

1. Degradation of emulsion – the processes of different etiology, initiation mechanisms, chemical and physical nature. Degradation leads to partial or complete destruction of emulsion (silver bromide gelatine emulsion, in this particular case) and formation of salt efflorescence (sodium thiosulfate, aluminium sulphate, and so on). Defect region may be of arbitrary form and size. The typical appearance is the “foam around the bubble”. Degradation is usually combined with exfoliation of different types (“radial”, “butterfly wing”, “spiral with waves”, “fern leaf”, “frosty patterns”, and other branchy patterns) and emulsion loss. At the initial stage of degrading the germ is usually about 0.5-3 mm in diameter and have rounded form, “M”- or bell-shaped intensity profile, and may have bright or dark halo. Salt efflorescence is a component of emulsion degradation with emergence of decay products in the form of powdered coating of different color and consistency on the emulsion surface.
2. Reticulation – a network of cracks or wrinkles in a photographic emulsion. As the emulsion gets older its fragments start flaking or peeling away from the base forming, e.g., “fern leaf” or “frost on a windowpane” patterns. Reticulation may be caused by different factors, e.g. too great a difference in the temperature of baths or between final wash water and the air in which the negative is dried.
3. Flaking emulsion – detachment of the emulsion from its base as a result of weakening of emulsion adhesion properties due to its ageing. The size of such defects may be from 0.5 mm to the whole frame. Some negatives in the Prokudin-Gorsky collection had flaking emulsion probably caused by the exposure to water during storage in the cellar of the apartment house in Paris before 1948 [8].
4. Scratches fall into three main categories. Emulsion scratches (usually look like bright lines on the negative); base scratches (usually dark lines on the negative); and deep emulsion scratches which also damage the base (usually bright lines with dark elements inside). Width of the scratches is mostly about 0,1 – 0,2 mm.
5. Abrasion marks consist of many hair-like fine lines arranged in cellular, concentric, or chaotic structures of different size.
6. Physical defects of “wet process”: air bubbles, emulsion shifts along the base with typical “waved smearing” of defect edges caused by the finger or tweezers contact. This group also includes traces of air bubbles or insufficient agitation of the negative during the development.
7. Pollution of different nature (greasy spots, dust, fingerprints, glue, dye, and other foreign elements sticking to the emulsion or to the base.
8. Biological damages – are often appearing as mould spots on emulsion.
9. Optical effects: caused by improper focusing or insufficient depth of field, blur caused by moving objects contour shifts, reflexes caused by glittering objects, parasitic flashes, lens glare, shadows from camera components.
10. Fogs – films on emulsion surface changing its optical properties. The following types of fog are typical for glass negatives: colloid silver film, dichroic fog, edge fog.
11. Mechanical damage of emulsion and base (cracks and fragmentation).

In the following section the technique for defect detection is considered.

3. Defects Detection

Taking into account the specificity of the triple colour photography technique, the following necessary condition for concidering 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, 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.

The technique for detecting local defects is based on a set of principles formulated taking into account: first, the specificity of triple colour photography technique, and secondly, the specificity of visual appearance of different defect types given in Section 2. The main principles of the detection technique are as follows. Detection of suspicious regions is performed separately in each component (R, G, B) of the registered color image. The exception is the group of defects (or artifacts) appeared as monochrome fragments. In this case the intensity values in all of the components are analyzed simultaneously. A set of techniques is used for detecting local defects. For detecting defects of a particular group a special technique can be applied. Application of a particular technique results in a binary mask image. Decision on labeling a suspicious region as a defect depends on the result of analysis of three binary masks corresponding to three components. Finally, a set of mask triplets is obtained.

For detecting regions with emulsion losses characterized by a very high intensity level or non-transparent regions caused by pollution and characterized by a very low intensity level, thresholding is applied. For detecting deteriorations appeared as dark or bright spots with rather smooth boundaries, a technique based on combined morphological opening and closure operations, is implemented [6]. Structural elements of two types of size 5x5 (one of them is flat with zero elements, and another one is non-flat) are used in morphological operations. For manual segmenting defect regions that cannot be found automatically, a snake-based segmentation technique is applied [9].

4. Correction

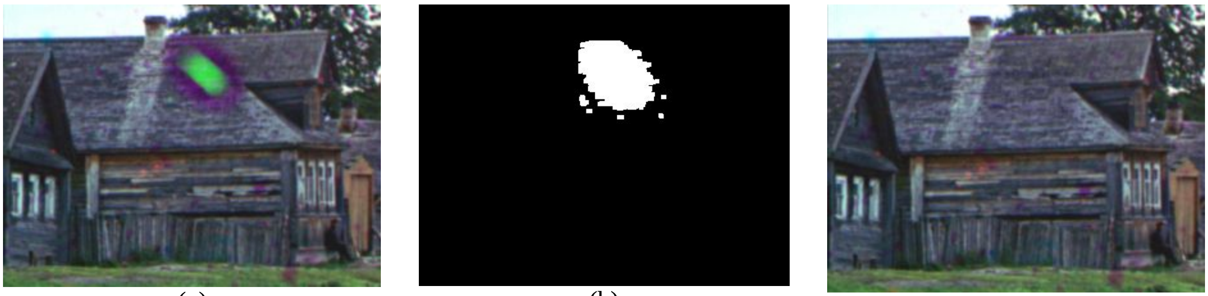
Correction of defects is performed using binary masks obtained at the detection step. Two different classes of techniques should be used. Techniques of the first class should be applied in case when restoration of lost fragments in one of triplet images is possible using information from correspondent regions in other images of a triplet. Methods of the second class [12] are necessary in case when the image fragments are lost in all of three images composing a triplet.

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

Unlike techniques for restoring movies using adjacent frames [6], in this case there is no need to find transformation between two frames for fragments registration because defect detection is performed in already registered images. The result of applying described algorithm is shown in Fig. 1.

Conclusion

The problems related to the reconstruction of historic images taken in 1900's by the technique of triple color photography are considered and solutions are proposed. The classification of defects in images acquired by scanning triple glass negatives is developed. The techniques for automatic defect detection and compensation are proposed and discussed. The future research will be aimed at the development of more precise techniques for defect detection and compensation.



(a) (b) (c)

Fig. 1. Image restoration: (a) initial image; (b) binary mask of a defect region; (c) restored image

Acknowledgements

The work is partially supported by the Russian Foundation for Basic Research, Grant N 06-07-89282.

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