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Towards the Automated Restoration of Old Photographic Prints: A Survey

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Abstract— **The ubiquitous fruition of cultural and artistic heritage in the field of photography requires as a first step the conversion of a huge amount of old printed material into digital form, for successive manipulation and data management. This process is particularly delicate for photographic prints, which *often show the effects of aging. This paper reports a list of the* principal defects that can be detected in an old photography; the different origins of them, and their different features, suggest different restoration approaches.**

Index Terms—**Advanced methods for image processing, cultural heritage, image restoration, defect detection.**

I. Introduction

Photography is a recent form of art, but probably the most diffused in the world. Since its introduction it has supplied us with a huge amount of documents of high cultural value. The ubiquitous fruition of such documents requires as a first step the conversion of old printed material into digital form, for successive manipulation and data management. Unfortunately, the oldest photographic prints are based on *fragile materials, which are affected by bad environmental* conditions. For this reason, in these years, the care for the preservation and conservation of prints has increased. However there are many damaged pictures that still need to be restored. With classical, physical restoration, the images are dusted and cleaned, the gaps are filled up, the emulsion is consolidated, the gelatin is fixed, and some parts are repainted by hand. This pipeline produces cleaner images, but is extremely expensive, and often the damage is still visible.
The diffusion of scanners and of software to manipulate the image opens a new way to the recovery of photos. The old image, after the digitization, can be virtually restored and, if necessary, reprinted. For this type of digital restoration, the goal is that a person viewing only the restored version should not be able to realize where the changes are. Notice that this case is different from the one of the physical restoration of originals, where the original artwork needs to be preserved. Commercial software exists, which proposes a heavy user-guided restoration, where the defects are not automatically traced, and also all the corrections must be user-suggested. Virtual restoration becomes complex and expensive, and it can be performed only by skilled personnel. Automated restoration is hence required to obtain quick, simple and effective results.
In this paper we propose a dissertation about defect detection and correction. It should be emphasized that at least three different advantages stem from the digital restoration of photographic prints:

- ubiquitous fruition is made easier, since a clean image typically can be much more efficiently coded and transmitted or stored;
- the performances of content description methods for the purpose of retrieval and browsing are improved;
- the visual quality of the output is improved, in particular on low-cost portable displays.

The rest of the paper is organized as follow: Section II suggests a classification scheme for all defects present in the image; Section III shows the algorithms for defects localization; Section IV summarizes the techniques to reconstruct the original image. Section V reports an application of an algorithm for scratches and cracks removal. A Conclusions section ends the paper.

II. Classification of Defects

The photographic print is what is usually called *positive* of the image. It is a sheet of paper with a mix of gelatin and nitrate of silver on the surface. The image is created by the sensitivity of the nitrate of silver to the light. The main cause of the imperfection in old prints is a careless conservation of the positive. Experts suggest [16] to store the pictures in *conditions of controlled temperature and humidity. Also*, prolonged exposure to bright light should be avoided, since it can modify the colors in the image until it appears bleached (Fig. 1).
The defects of old photographic prints can be divided in different sets according to their origin.

- *Mechanical damage*: all the defects that are originated by an inaccurate handling are considered in this category. More in detail:
  - *Cracks* severely deteriorate the aspect of a picture, because they can be very large. Usually, they do not exhibit a dominant orientation, even if each single crack follows its own direction (fig. 2).
  - Old photos are often plagued with numerous *scratches*. They are thin straight lines without a

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preferential direction (fig. 3).

- Over the years the photographs are often folded or torn. Even if all the pieces are available they may not correspond perfectly. In the scanned image the result is similar to a crack. Moreover, if some part is lost, there is a gap in the image (fig. 4).
- There are several deliberate human retouches or manipulations that irremediably damage the image, like holes or added stamps and text (fig. 5).

- *Chemical damage.* All the defects that belong to this set are originated chemically. They are:
  - *Semi-transparent* blotches, often originated by water or humidity (Fig. 6). In this case, each pixel in the blotch contains both information about the real data and noise.
  - Gaps over the image (fig. 7) originated by attacks of chemical agents to gelatin. These kinds of blotches create regions with homogeneous gray level. Blotches can be considered very critical which involve particular positions of the image, like a face (fig, 8).
  - "*Foxing*": in some picture it is possible to note reddish-brown spots (Fig. 9). This phenomenon is the result of chemical reactions between the print and some microorganisms [7].
- *Deposited matter.* Different materials adhere to the surface creating small spots that cover the original image (fig. 10).

Once the photographic print is scanned, the defects are part of the digitized image too. For the automated detection and restoration their origin is important only as far as it affects their geometric characteristics like width, length or gray level. For this reason it is usual to cluster all the defects into three groups: blotches, cracks and scratches. Moreover, since digital restoration may use residual information in the prints, it is important to observe that only semi-transparent blotches preserve part of the original information; all the other defects imply a complete loss of the information.

It should be mentioned that, while the scientific literature devoted to photographic prints defects is scarce, a big effort has been devoted to the restoration of old movies. As an example some indication about these techniques is reported in [13], [17]. Unfortunately, even if some defects seem to be shared with photographic prints, they present different features. For example, scratches in image sequences typically present a vertical direction, because they are originated by abrasion in the transport mechanism. In photos they do not have a preferential direction.

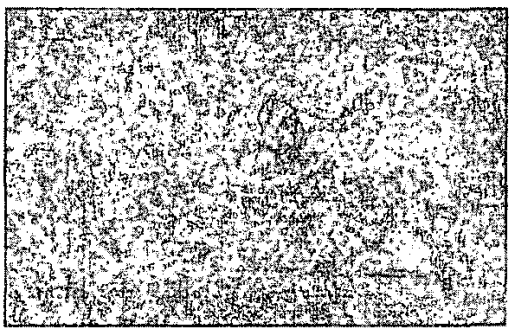

Figure 1 – The image appears bleached due to the prolonged exposure to the light.

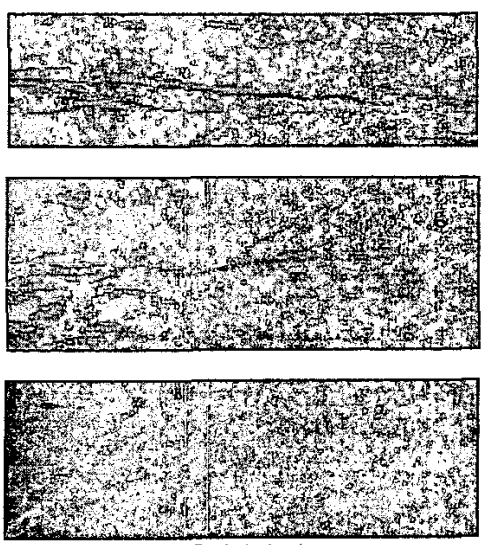

Figure 2 – Cracks in the picture.

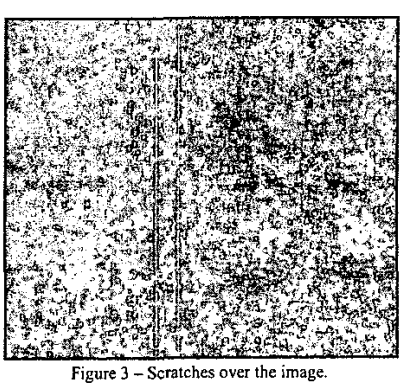

Figure 3 – Scratches over the image.

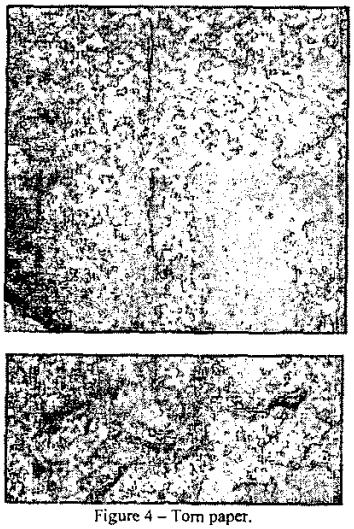

Figure 4 – Torn paper.

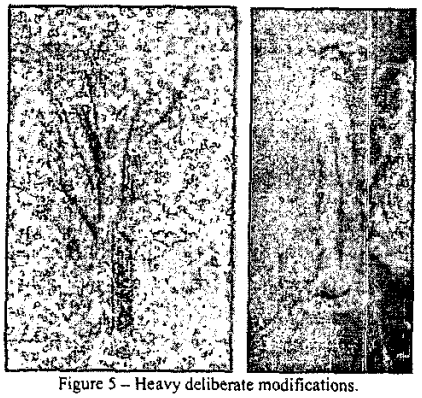

Figure 5 – Heavy deliberate modifications.

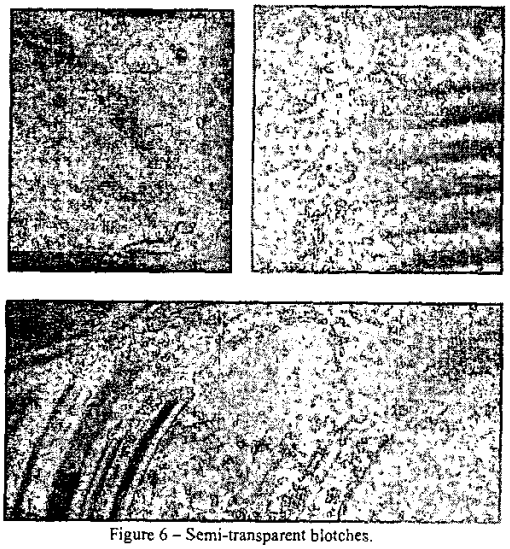

Figure 6 – Semi-transparent blotches.

Figure 7 – Chemical attacks which destroy the original information.

Figure 8 – Definitive loss of information.

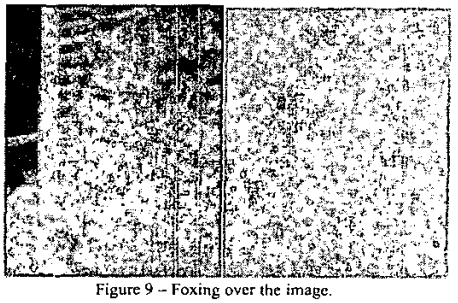

Figure 9 – Foxing over the image.

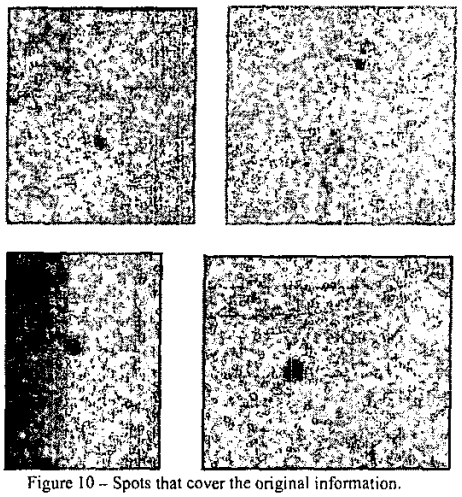

Figure 10 – Spots that cover the original information.

III. Detection

The defects presented in the previous section (blotches, cracks, scratches) are very difficult to automatically detect, since there are no simple rules to distinguish them from real image features. In particular, for crack identification in textured zones [18] and [19] suggest to compute a parameter for pixels in a perfect texture; then crack pixels are detected using a distance measure from the estimated distribution of defect-free pixels. In [5] the image is mapped into a special data structure, which represents the skeleton structure of the texture. Based on the skeleton information several statistical measurements are performed. According to the difference between the observed and stored measurements, various defects can be detected and located.

In a non-textured zone, where it is impossible to automatically distinguish between cracks and lines belonging to the picture, users must manually select a point on the crack [2]. Barni et al. consider cracks darker than the background and with a uniform gray level. Tracking is accomplished on the basis of two main features: gray level and crack uniformity. Once the system knows some pixels belong to a crack, it assigns new pixels to the crack if their gray levels lie in a given range and do not differ significantly from those of the pixels already classified as belonging to the crack.

As mentioned above, a big effort has been devoted to the restoration of old movies. It is possible to use some algorithms for old prints. For scratches detection [13], [17], [20] suggest analyzing a one-dimensional function depending on each column. Candidate scratch lines are in columns where the variance shows a local fluctuation.

Commercial software exists that automatically detects and then removes dust and scratches [11]. It needs to specify whether the defects appear light or dark, the size of the region used to gather statistics about the defects, and the amount of degradation. Notwithstanding the good quality of the results, it can happen that some defect is not removed, and hence a manual retouch is necessary.

Finally, it should be observed that digital scanners exist which have new technologies like Digital ICE (Image Correction and Enhancement) [8] or FARE (Film Automatic Retouching and Enhancement) [9] to detect damages. They add a fourth information source to the standard RGB scan, which is used to calculate and subtract the non-image information from the data. However these scanners can operate only with transparent films and not with photographic prints.

IV. Restoration

Normally, to restore an old picture, professional operators use commercial software like Adobe Photoshop™. This kind of restoration is heavily user-guided because the defects are subjectively detected and the type of correction is user-selected too. This task is complex, expensive, and acceptable only for particularly important pictures. An automated system based on algorithmic restoration could facilitate the non-professional restoration.

The problem of disocclusion (i.e. the recovery of hidden parts of objects in a digital image) is a problem similar to the blotches removal. A possible solution is to connect T-junctions at the occluding boundaries of objects with elastica minimizing curves [14]. The inpainting algorithms [1], [3], [15], use and improve on this idea. They propagate both the gradient direction and gray-values of the image in a band surrounding the hole to be filled-in. Isophote (region with the same level lines) directions are obtained by computing at each pixel along the inpainting contour a gradient vector and by rotating the resulting vector by 90 degrees. This intends to propagate the information while preserving the edges. After few iterations of the inpainting process, the algorithm performs an anisotropic diffusion run to preserve boundaries across the inpainted region.

Several methods exist to remove blotches using probabilistic algorithms. In [6] the missing areas are corrected by reshaping the Fourier spectrum of the regions of interest according to a reference spectrum. The user must carefully select this reference spectrum. The algorithm introduced in [4] extends the previous idea to natural images, and runs without user intervention.

Also for restoration there are numerous algorithms proposed for video sequences. However, they normally rely on the existence of information from several frames [13], [17], [22]. Even if this is out of our range, some techniques operate in two dimensions and can be exploited. To restore a line scratch, trivial solutions like a horizontal median filter or simple linear interpolation can be proposed. However they produce evident artifacts. For this reason more sophisticated approaches have been introduced. In [20] each pixel on a scratch is assigned the gray level value satisfying a fitness function based on color information. This fitness function tends to reduce the gap between line scratches and the rest of the image. A genetic algorithm produces the optimal values for the pixels on the scratch. The starting population is a two-dimensional mask centered on the scratch and including a set of neighbor pixels outside the scratch. In [12] the scratches are removed applying a nonlinear operator. The minimum of two sums between horizontal neighbors is selected for bright vertical line removal. However the restored image becomes blurred as the size of the mask becomes larger. The Line Scratch Correction Algorithm (LSCA) proposed in [21] is an additive-multiplicative model to correct vertical line scratches. It reconstructs the low-spatial frequency components of the image via an approximation of the uncorrupted image, and the high-spatial frequency components by means of a particular additive-multiplicative model.

V. Retouching Lines

Scratches and cracks removal is hence a relevant issue in photographic print restoration. The LSCA method [21] above introduced is meant to correct vertical line scratches in old

movies; however, it can be applied with some success to correct almost straight cracks in photographic prints too. Fig. 11 shows some results. Here the operator has been applied in two different, user-defined image locations: vertically, in correspondence of a vertical straight black scratch located approximately in the middle of the picture, and horizontally in the area of a much wider crack below the man's belt. The results show that the vertical scratch is perfectly removed, and the cracks removing gives an acceptable result, even if a perfect reconstruction of the area under the defect is not achieved. Moreover, it is important to observe that the LSCA does not follow the crack if this drifts outside the area which has been selected by the user. For this reason the crack over the sleeve on the right of the print is not corrected even if it is part of the same crack.

The LSCA operator can be generalized to retouch cracks in any direction, and to adjust only the pixels over the scratch following its course.

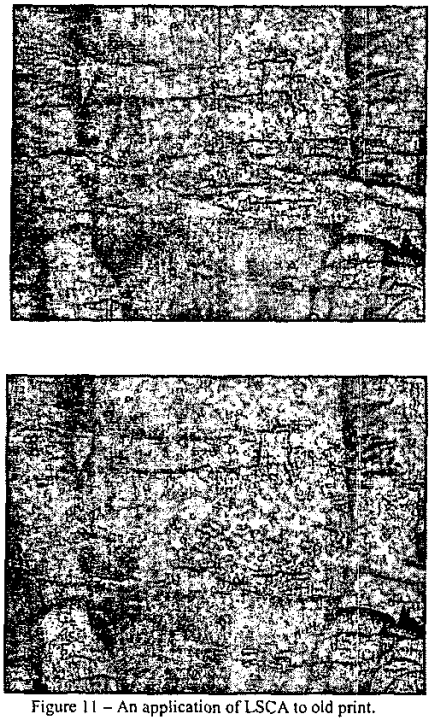

Figure 11 – An application of LSCA to old print.

VI. Conclusion

In this paper we have proposed a classification of defects in old photographic prints according to their origin. There are also reported some algorithms for defect detection and restoration. For scratches removal and cracks we have proposed to apply the LSCA algorithm, that produces good visual results.

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