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Original article

Automated restoration of semi-transparent degradation via Lie groups and visibility laws

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Abstract

This paper presents a novel approach for the removal of semi-transparent defects from images of historical or artistic importance. It combines Lie group transformations with human perception rules in order to make restoration more flexible and adaptable to defects having different physical or mechanical causes. In particular, the restoration process consists of an iterative procedure that gradually reduces the visual perception of the defect. It takes advantage from Lie groups that allow to define a redundant set of transformations from which it is possible to automatically select the ones that better invert the physical formation of the defect. Experimental results on movies and photographs, affected by line-scratches and semi-transparent blotches, have shown the potential of the proposed approach in giving new guidelines and trends for human perception-based restoration.

Keywords: Automated digital restoration; Human perception; Lie groups; Semi-transparent defects

1. Introduction

The increasing diffusion of cheap electronic devices has produced a complementary need of effective fruition frameworks [1]. These latter have to be:

- automated, since the user is not required to be able to manage an application with one or more parameters to tune, and
- low cost. This requirement is twofold. On the one hand, a fruition process should be cheap enough to allow a wide commercial diffusion; on the other, it must have a low computational effort in order to be uploaded or embedded in portable devices like smartphones.

From a research point of view, the development of a really fruitful system consists of making its components user independent that is not a trivial problem. Digital restoration is one of the main tasks of this fruition chain [14]. Though

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this (sub)problem is far from being solved, it is possible to achieve satisfactory results for some specific classes of images. One representative example is the class composed of digitized copies of ancient manuscripts, old photographs and films, stamps, or more in general, archive documents of historical importance [4]. This class of images is usually affected by different kinds of damages such as noise, line-scratches, tear, moire, blotches, shake and flicker – see [4,9,11,15,16,19,18,27,24,25,23,10,26,28]. Among them, semitransparent degradation, that includes line-scratches and blotches, is of particular interest for the objective of this paper. In fact, this kind of degradation affects a subregion of the document but does not completely hide the underlying original information. This is the reason why classical detection operators may, in principle, confuse it with the scene content. At the same time, its elimination or reduction cannot be performed by classical restoration operators or inpainting methods [14,2,12] since the original image content must be retained for its historical and artistic value. However, the preservation of part of the original content in the degraded area gives a sort of objectivity to the final restoration result – even though it is only based on visual inspection. Another positive aspect of this kind of defect is that it is perceivable (by human observers) at a 'first glance' over the image: its elements are recognized as 'foreign' objects in different contexts over the same image. This is a key point as it allows us to change the paradigm of the restoration process, that can now be the 'reduction' instead of the 'elimination' of image anomalies, independently of a priori information about the image or the defect. In fact, it is well known that the deeper the knowledge about the formation of degradation, the lower the dependence of the restoration on the original image. Semi-transparent degradation allows us to make a step forward in studying and deepening the possibility of making the restoration as automated as possible, as no longer based on hypotheses on both the image at hand and the defect to eliminate. The core of the restoration process is then moved to the perceptual content of the image under study and to the reduction of all its perceptual anomalies. To this aim, starting from some pioneering papers in this sense as [4–6,3], the role of Human Visual System (HVS) in the restoration process has to be emphasized further by introducing proper mathematical concepts and tools. This paper represents a first contribution to this challenging purpose.

Specifically, the objective of the paper is to define a new restoration process that tries to further reduce the a priori knowledge about the degradation under exam. In order to make automatic the reduction of the visual contribution of the defect, the proposed model selects suitable transformations from a redundant set of available ones. A primary advantage of adopting this philosophy is that the same restoration algorithm may be used for a wide class of image degradations. This peculiarity is completely novel in the literature, since all classic restoration models use specific and oriented operations for the specific case under study. A local contrast-based restoration process that embeds transformations in a Lie group gives us the opportunity of defining a redundant set of transformations that also contains the inversion of the unknown degradation process. In addition, it allows to develop a restoration algorithm that automatically selects the more suitable transformations for points having the same visual contrast. Apart from the novelty in the way of performing the restoration, the proposed model has two main advantages with respect to competitive approaches available in the literature:

- the combination of HVS and Lie algebra allows the proposed restoration model to have not a precise target to converge. This is an attractive feature useful for degradations that have not a precise characterization. In practice, the proposed model forces the contrast of the final solution to be in a suitable range of values according to typical contrasts of the surrounding clean image, exploiting the fact that the degradation should be made invisible;
- the nature and the variety of Lie group transformations permit to work in the physical (image) space rather than in a projection one and to exploit a more flexible model of restoration rather than simple transformations like translation and shrinking – usually adopted for their simplicity rather than their efficacy [4,15,24].

Moreover, the proposed model can also be of interest in several applications since it promotes and facilitates its use by non-expert people and, at the same time, it avoids the development of integrated software tools able to deal with specific kinds of degradation.

The paper is organized as follows. Next section gives a brief review about the semi transparent degradation. This short introduction allows the reader to better understand the novelty in its removal process. The main guidelines of this new restoration paradigm are contained in Section 3, where the motivation of the proposed approach is presented. Section 4 offers a sketch about Lie algebra and Lie group transformations, without many mathematical details but sufficient to understand the rest of the paper. The proposed restoration model is then described in Section 5 and the