Spatial image processing for the enhancement and restoration of film, photography and print

Carinna Parraman
Centre for Fine Print Research, University of the West of England, Bristol, BS3 2JT UK

Alessandro Rizzi
Department of Information Technology, University of Milano, Via Bramante, 65-26013 Crema (CR) Italy

Abstract

This paper presents a review of research undertaken into algorithms for colour enhancement methods based on the behaviour of the human vision system and the applied research in film, photography and print. These colour enhancements methods perform automatic adjustments that are based on the content of the image without the need of any statistic or a-priori knowledge about it. We have found that it can have a range of benefits and implications for enhancement of new images and restoration of deteriorated images. This paper presents an overview of series of research projects that have been undertaken since 2005 and which are still being explored as new algorithms are being introduced and refined. The paper will discuss the strengths and limits of this approach.

1. Introduction

Film, photography and print are important for capturing and recording a huge range of activities for art, entertainment, advertising and documentation. However, these materials – dyes, inks, papers, film-stock, digital data, are also subject to change and deterioration and it has become increasingly important to preserve our recent photographic and printed cultural heritage. In order to obtain a good quality image or a restored image, the process of adjusting images can be a time consuming and a costly procedure. In this paper, we consider the use of unsupervised colour enhancement methods as final automatic processing or pre-processing for printing.

We tested some classic widely used algorithms such as Histogram Equalisation and Auto Levels and compared them to alternative approaches that utilise Spatial Colour Algorithms (SCA). The term Spatial Colour Algorithm refers to a family of algorithms that re-compute wavelength/energy arrays into calculated colour appearance arrays, or preferred color enhancement arrays, according to the spatial distribution of pixel values in the scene [1]. Their basic idea is to mimic the behaviour of the human vision system.

Among these algorithms, we present the following: Retinex [2-4], RSR [5], ACE [6]. SCAs are generally parameter dependent [1]. We do not intend to consider fine tuning for each of the techniques, rather to consider an average parameter set for each one and then test if this approach can go in the user preference direction. Previous preliminary tests of this approach on display and prints are reported in [7-10]

2. Scenarios and problems

The following examples demonstrate the range of scenarios and problems that have been considered and addressed.

2.1. Film restoration

Wet-process film materials are the result of a chemically unstable process, subject to fading over time. This fading is irreversible and in several cases photochemical restoration of faded prints is problematic and not always possible. In these cases, digital colour restoration can address the problem. Faded film images are dull, have poor saturation and an overall colour cast. This is due to the bleaching of one or two chromatic layers of the film. Since it is necessary to deal with lost chromatic information, restoring the colour of faded movies is more complex than a simple colour balance.

Digital techniques allows easily multiple restoring solutions, but still the restoration process can be a very delicate and long process, based mainly on the professional personal skills of the restoring technicians. The restoration market demands for automatic solutions, but the big diversity of all the possible film conditions makes every automatism difficult to implement.
2.2. Image enhancement for the printing of digital photographic images

User objectives for digital capture have more far reaching objectives: documentation, collection of images for recording, uploading to Internet, dissemination of images, prints and artworks through the Internet, recording of events and preparing images in preparation for printing eg. wedding or holiday albums, the process of selecting images therefore reflects these requirements.

2.3. Limited devices or non standard external conditions

As more spontaneous images are captured by phone, events may be captured in an environment that is under poor or artificial lighting conditions. The intention is to consider a range of photographic conditions and reasons for image capture, such as artefacts that are poorly lit (possibly due to museum or conservation issues), conditions where flash photography is prohibited or unsuitable, scenes taken in artificial light conditions, de-saturated scenes, atmospheric influences, photography of flat artworks, objects taken against a white background and underwater photographs are sampled.

2.4. Image enhancement for drawings, artworks and digitally generated images

As artists, designers and archivists require scanning and photography of artworks and artefacts, these might be used for digital archives, for the Internet, promotional materials. Some might be flat scanned, such as maps or small prints and photographs, and some might be very large that it is difficult to obtain a uniform lit surface. These artworks may be textured or collaged, digitally generated or manipulated artworks, black and white prints, commercial CMYK prints, newspaper images, scanned artwork, colour photographs, black and white photographs, (see Figure 1).

2.5. Image restoration of faded fine art prints

For artists and conservators who need to restore the print to its original condition would benefit from the assistance of colour restoration tools to reproduce colours that are as close to the original as possible. This can be undertaken for instance using a model of dye or pigment fading. The problem in these cases is to solve how to estimate the amount of fading. In many cases, an original is not always at hand for comparison, which presents a problem as to the original colour. In this paper we suggest the use of techniques that aim to restore the colour appearance and not the colour itself.

3. Description of colour enhancement methods

In this paper we work with two categories of image enhancement methods. The first are classic global enhancement methods that are included in photo editing software which enables the user to adjust brightness, saturation, contrast by hand and in digital imaging software such as Photoshop: histogram equalisation, auto levels and auto-colour. This global approach maps every pixel using the same value.

The second is a spatial image enhancement approach (SCA), which is inspired by human visual system characteristics and share both global and local colour correction characteristics. This method makes a pixel-by-pixel comparison to re-compute the pixels based on the context of the scene. Considered examples are Retinex, RSR, ACE. The main characteristics of these methods are described here in more detail.

3.1. Histogram equalisation and curves

In commercial software applications, such as Photoshop, there is a range of tools for the fine-tuning of an image. Therefore, improving the dynamic range of an image can be undertaken using the histogram in Levels by changing the input and output levels; or through Curves by adjusting any point on a 0-255 tonal scale; or by assigning target values to the highlight and shadow pixels using either the Levels of Curves.

Photoshop automatic tools process the image on a global level, therefore making an assessment of an image by building a histogram, and applying corrections to the whole image. As demonstrated in figure 1, by stretching the black and white points, a brighter image is obtained. In the lower image, the histogram shows peaks in the black and white and nothing in between. However, using auto levels to an image that has high contrast no improvement is made to the mid tones (Figure 2).
3.1. Auto Levels

Auto Levels defines the lightest and darkest pixels in each colour channel as white and black and then stretches the in-between pixel values proportionately. Because Auto Levels adjusts each colour channel individually, it may remove or introduce colour casts.

3.2. Auto Colour

Takes an average distribution from the darkest, midtone to the lightest areas of an image, by neutralising the midtones and clipping the white and black pixels.

This can be undertaken in Curves on a more precise level by assigning up to 14 points on a curve, or by using the auto levels. Because each channel is adjusted individually, the algorithm may remove or introduce colour casts.

3.3. Retinex

Based on the human colour perception system, the term is a composite of ‘retina’ and ‘cortex’. The Retinex algorithm, mimicking human vision, computes image colour appearance, and is described by Edwin Land in 1971 [2]. It performs global and local filtering according to the way it scans the input image. Several implementations have been developed so far [4].

3.4. RSR

Random Spray Retinex, (RSR) [5] is one of the implementations of the original Retinex model. In this implementation, locality is performed by random sprays of a target point rather than paths.

3.5. ACE

ACE [6] is an algorithm for unsupervised enhancement of digital images. The implementation of ACE follows the classic SCA scheme: the first stage re-computes each pixel according to the content and the relative position of the values in the image while the second stage map the computed pixel values into the available device range.
4. Test setup and results

We present some results for each one of the described test study. Some of the results have been previously presented in [7-10]. We concentrate in the last section, presenting new preliminary results and comments. The parameters used for these tests were:

Table 1. ACE Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter range(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subset selection</td>
<td>Sub-sampled at a sub-factor of LL2</td>
</tr>
<tr>
<td>Chromatic comparison</td>
<td>SL5</td>
</tr>
<tr>
<td></td>
<td>SL20</td>
</tr>
<tr>
<td></td>
<td>Sign</td>
</tr>
<tr>
<td>Distance</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 2. Retinex Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter range(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub sampling factor</td>
<td>4</td>
</tr>
<tr>
<td>Number of random paths</td>
<td>20</td>
</tr>
<tr>
<td>Type of path</td>
<td>Brownian</td>
</tr>
</tbody>
</table>

Table 3. RSR Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter range(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of spray per pixel</td>
<td>5</td>
</tr>
<tr>
<td>Number of point per spray</td>
<td>500</td>
</tr>
<tr>
<td>Type of spray</td>
<td>Random</td>
</tr>
</tbody>
</table>

4.1 Film restoration

To implement a standard tuning procedure, we extracted a set of still images (key frames) that summarise the video content in a rapid and compact way. Different methods can be used to select key frames. In general these methods assume that the video has already been segmented into shots by a shot detection algorithm, and extract the key-frames from within each shot detected.

After the extraction of key frames, these images are used as a set for the parameter tuning of ACE, the chosen algorithm for colour correction. By default the key frames are used to set the colour correction method parameters, which are then applied to the whole shot. Due to the robustness of the colour correction method the setting used for the key frames is used successfully for all the frames of the same shot [11]. Figure 4 shows the application of ACE on a black and white film in order to restore its original dynamic range. The example is from Tom Tight et Dum Dum (1903) by Georges Méliès. In figure 4 the relative histograms are presented.

![Fig. 4. Application of ACE on a black and white film. a) Original frame from “Tom Tight et Dum Dum”. b) Frame filtered with SLOPE=20.](image)

4.2 Image enhancement for the printing of digital photographic images

An investigation was undertaken to assess whether an automatic solution could be obtained that could enhance out-of-balance images to obtain images that were more natural and pleasing. The project [10] sampled 13 images, and project [9] from an initial set of thirty images, ten were chosen for printing, which was due to the other images showing similar characteristics. All images were subjected to a range of spatial and non-spatial parameters. The same parameters were set for each test set. The images are captured on a flat bed scanner, digital camera, or are digitally generated on computer. All are constrained to the same file size of 2MB, and saved as 24bit RGB images.

In order to assess the automatic methods for correcting images, a series of high quality printed sheets of each image were made, which contained all of the spatial and global sample variations. A questionnaire was devised to gauge preferences of the artist, technical expert and the general user, with the intention for extending the application as means for improving workflow and colour management systems prior to printing.

![Fig. 5. Relative histograms of frames in Fig. 3](image)
4.3. Limited capture devices or non standard lighting conditions

Fig. 6. Example of a printed sheet ‘Church’, 8 sampled images are placed in a random order

Fig. 7. Example of a printed sheet ‘Angel’, 8 sampled images are placed in a random order

Fig. 8. Detail of ‘Angel’ from printed test sheet, showing the application of ACE at varying parameters: A) The original image B) ACE SLOPE=5 C) ACE SLOPE=20 D) ACE SIGN

Figures 6 and 7 illustrate two images taken under different lighting conditions. In figure 6 the sample image Church, where flash was disallowed, the only light source is the illuminated figure and the surrounding environment is in darkness. The second image Angel (figure 7) is a painting on a wood panel, which is displayed in a museum where flash photography is not permitted and therefore the original photographs of both Church and Angel appeared de-saturated and dull.

Gold is a colour that is particularly difficult to reproduce and print, and so the balance or brightness of gold in relation to the rest of the image might be considered as: too bright, overpowering, too dull, not convincing as gold. The red might also be an aspect that is subject to comparison: the red tunic of the figure, the red line along the top of the painting; the red of the carpet around the altar, the red lights on either side of the altar. Does the red in both the images stand out as dull,
balanced or too bright? Lastly, large flat areas of chromatic dominance, which contains little information could be problematic: for example, situations where art works are photographed against a white background or where the light source is uneven, might results in pooling or halos of light. This is particularly obvious in figure 7.

4.4. Image enhancement for drawings, artworks and digitally generated artworks.

As described in projects [9] and [10] (section 4.2) sampling included: scans of woven textiles, collage, newspaper prints, drawings, etchings, as well as digitally generated images, black and white images that had been converted from colour. These were subjected to the same range of spatial and non-spatial parameters.

In the scan of Drawing (figure 9), the most preferred enhancement method by users was Random Spray Retinex (RSR), which increased the whiteness of the paper and the brightness of the coloured marks. If compared to the auto-levels whilst the image is brighter than the original the green pen marks appear darker and more contrast.

4.5. Image restoration of faded fine art prints

For this research project, we had access to a collection of both exposed an unexposed fine art prints. The exposed prints are works that have been on display, under glass and in the same north-east facing position since 1991. The unexposed prints are from the same edition, which have been stored in a print archive at the Centre for Fine Print Research. It was very useful to gain access to a collection of works that had been subjected to the same conditions over the same period of time, to be able to gauge how fine art materials such as paper, ink and process, fared over time. Furthermore it was equally significant to be able to compare the faded prints to a set that had not been exposed to light, heat and humidity. The following example demonstrate the extend of fading of an early inkjet print.

Fig. 10. Example of a 3-colour inkjet fine art print made in 1991. All the channels have faded except for the cyan. The faded sample can bee seen in the bottom left-hand corner. Through the application of ACE slope=5, 20 and Sign, Yellow and Black have been recovered.
These prints demonstrate a range of traditional (etching, stone litho) and more contemporary print methods of that time (screenprint, 4-colour-offset litho, laser-print, inkjet). Due to the use of fugitive inks some of the contemporary printing methods (4-colour-offset litho, laser-print, inkjet) the magenta, yellow colours have considerably faded resulting in two cases in which just the black and blue layers remain. It was thought to be impossible to restore these as no actual colour residue remained on the print.

All images were subjected to the same parameters and were printed on the same printer onto fine art paper, using the same settings. For this experiment, only inkjet printing was used to emulate all the traditional print processes. Users are asked to identify their preferred print in relation to lightness, tonal range, colour range, quality of detail and overall subjective preference.

There were some surprising results for 4-colour images even where only one of the four colours remained. Through the application of the spatial algorithm of ACE, some traces of the yellow and black channel were recovered as demonstrated in figure 10. Also as exampled in other monochrome images, contrast and dynamic range is improved (figure 11)

![Fig. 11. Example of monochrome fine art print using ACE slope=5.](image)

5. Conclusion

As demonstrated in the figures included in this paper, the use of spatial enhancement methods such as ACE, Retinex an RSR can assist in improving the balance an detail of both film, photographs and fine art prints. In general it was found that ACE fails with images that have a particular chromatic dominance, in this case, colour is significantly changed and can result in a better image but with an extreme colour shift. Fine-tuning of the parameters in order to obtain these results requires some knowledge of the strengths and weaknesses of each of the algorithms. Where an increase in brightness of contrast was required for photographic images, in many cases global image enhancements were the most suitable and all that was required.

It was generally found that for the majority of black and white images the spatial correction methods were strongly preferred (figure 4 and 11). Also for low dynamic range images, such as those taken under low lighting or poor atmospheric conditions, more contrast and detail could be discerned (figure 6 and 7). Significantly, it has been demonstrated that the spatial image enhancement methods are able to achieve surprising results in regenerating an image from a single channel to three (figure 10).

References

Notes in Computer Science, Volume 3736, Dec 2006, Pages 1 – 12.