COMPARING X-RAY AND BACKLIGHT IMAGING FOR PAPER STRUCTURE VISUALIZATION

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Abstract – In order to determine the authenticity of art works on paper it is important to inspect the paper structures and possible watermarks, because it provides information about the dating of the paper. Visualization of these structures is important. In this paper two visualization methods are compared: x-ray and backlight imaging. X-ray imaging leads in general to images with good quality, but it is quite a complex and expensive method. Backlight imaging is an easy and cheap method, but the quality strongly depends on the print or picture itself. These methods are compared qualitatively by art experts and quantitatively by means of image analysis techniques.

1. INTRODUCTION

In art historical research of etchings and other art on paper, analysis of the paper structure plays an important role. It helps answering questions concerning their dating and authenticity. In paper analysis especially attention is paid to watermarks and the so-called chain and laid-lines, which are the imprint of the mould or sieve used during the paper production process. Whereas initially paper analysis was only done by visual inspection, since more than 20 years ago different x-ray imaging methods, like electron-radiography, betaradiography and soft-x-ray methods [4], are employed to make the paper structure visible. Advantage of x-ray technique is that it can show the paper structure itself, while the image or print itself is suppressed.

A drawback is that rather expensive x-ray devices are needed. For that very reason, the generation of x-ray imagery is only within reach of the larger museums and art historical institutes. That is pity, since at this moment one strives for the generation of large databases of 15th, 16th and 17th century papers used by European artists, by linking existing databases [5] like those of Briquet of Piccard, the Royal Library in The Hague, Piccard-online in Stuttgart, WZMA in Vienna, and by generating new ones.

In general, the more samples a database contains the more useful it is. Thus it is imperative that also smaller museums and private collections make their collections available to let grow the number of samples fast.

A more simple solution in order to make the paper structure visible is the use of backlight techniques. On the market there are backlight foils available which produce a monotonic light. Especially in the East European countries they are used for paper and watermark analysis. The paper is put on the backlight foil and with a digital camera an image is made. This image shows partially the paper structure as well as the print or drawing itself. Then a picture of only the print is made. By ‘subtracting’ both images and by application of image enhancement techniques a new image can be obtained which mainly shows the paper structure.

The backlight imaging method is so easy to use that researchers can create an image almost realtime. It is portable and can be easily deployed in locations around the globe. This method leads to renewed interest in watermark and paper research through the ample availability of samples. It makes the research independent of large organisations by putting an important tool within the reach of the individual historian. There is also another advantage. Film- and film-less x-ray-imaging methods are in general limited to smaller formats. This is no problem for smaller prints but an old atlas from the ‘Hanse-time’ or reconstructed drawings from the renaissance of baroque would not fit. The backlight method, in contrast, has no problem with such large formats. They are readily available for form factors up to A0.

In this paper both x-ray and backlight imaging techniques are compared in terms of their quality. This is done by visual inspection by art experts as well as by a more technical and quantitative approach. Three types of paper are used for the comparison: blanco paper, one-side printed or written paper and two-sided printed or written paper.

The organization of the paper is as follows. First the imaging techniques are considered in section 2. Section 3 contains the comparison by the art experts and section 4 a quantitative comparison. Finally, in section 5 a discussion and some concluding remarks are made.

2. IMAGING TECHNIQUES

2.1 Soft X-ray Imaging

The x-ray technique used in this paper is one of the most advanced methods available at this moment. Since ink mainly contains carbon and carbon is rather insensitive for x-ray, x-ray imaging techniques are very suitable to visualize the paper structure without visualizing the print itself. This is the main reason to use x-ray imaging techniques. By means of this imaging technique it is even possible to achieve high quality images of the most difficult class of paper; those of the 17th century.

The used x-ray image generation technique consists of two steps. First the x-ray apparatus itself radiates low energy x-ray through the paper to a phosphor plate. Usually low radiation x-ray energy is absorbed by air, therefore a helium cone is placed between the x-ray source and the paper. The x-ray source is feeded with 5keV and 10mA, with a radiation time of 2 minutes. It took years of research for the art experts and radiologists to develop this method, see Van Aken [2]. The next step is reading out this phosphor plate by a laser reader, originally used for dentistry. Generation of an image takes about 4 minutes. These images are directly available in digital format and do not require any post-processing at all.

2.2 Backlight Imaging

In the case of backlight imaging a paper (with print) is put on the backlight foil and with a digital camera a digital backlight image B is obtained, consisting of pixels x_k with $k=1,..,K$, the pixel index and K the total number of pixels in an image. The intensity of each pixel x_k is denoted by $\underline{b}_k = \underline{b}(x_k) = (\mathrm{R}(\underline{b}_k), \mathrm{G}(\underline{b}_k), \mathrm{B}(\underline{b}_k))$, whereby the elements of the vector are the RGB-components. The image B shows partially the paper structure as well as the print or drawing itself. Then the picture of the original print is made. This image is denoted by O, with intensities $\underline{o}_k$. By subtracting both images and by application of appropriate image enhancement techniques a new image can be obtained which mainly shows the paper structure.

For our experiments we used a backlight foil of format A4, a Canon Ixus 500 digital compact camera (5 Mio pix.), a 135cm Manfroto tripod and 2 desk lamps. The reconstruction of the paper structure on the basis of *B* and *O* is done in the following way.

The pictures generated by the digital camera are represented in the *RGB* colorspace. This colorspace is not useful for the reconstruction, because the intensities of the print in both *B* and *O* in general do not match for subtraction. This can be handled easily within the intensity (*I*) channel of the *HSI* colorspace. The intensity channel of the backlight image is defined as a pixelwise operation on the *R*, *G* and *B* channels:

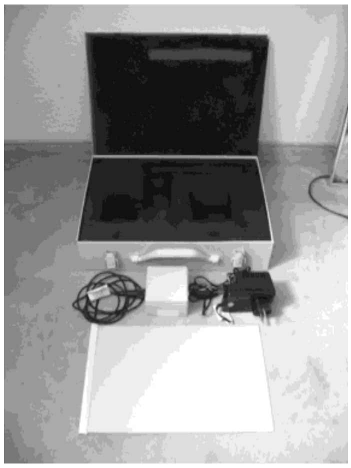

Figure 1. Backlight foil.

$$I(\underline{b}_k) = (R(\underline{b}_k) + G(\underline{b}_k) + B(\underline{b}_k))/ 3. \qquad (1)$$

In these images the intensity of the print appeared to be equal to each other. This is due to the fact that the intensity of black content is invariant to lightning conditions as long as the lightning is uniform. So, the paper structure image *Y* is obtained by subtraction of the intensity channels of *B* and *O*:

$$y_k = I(\underline{o}_k) - I(\underline{b}_k). \qquad (2)$$

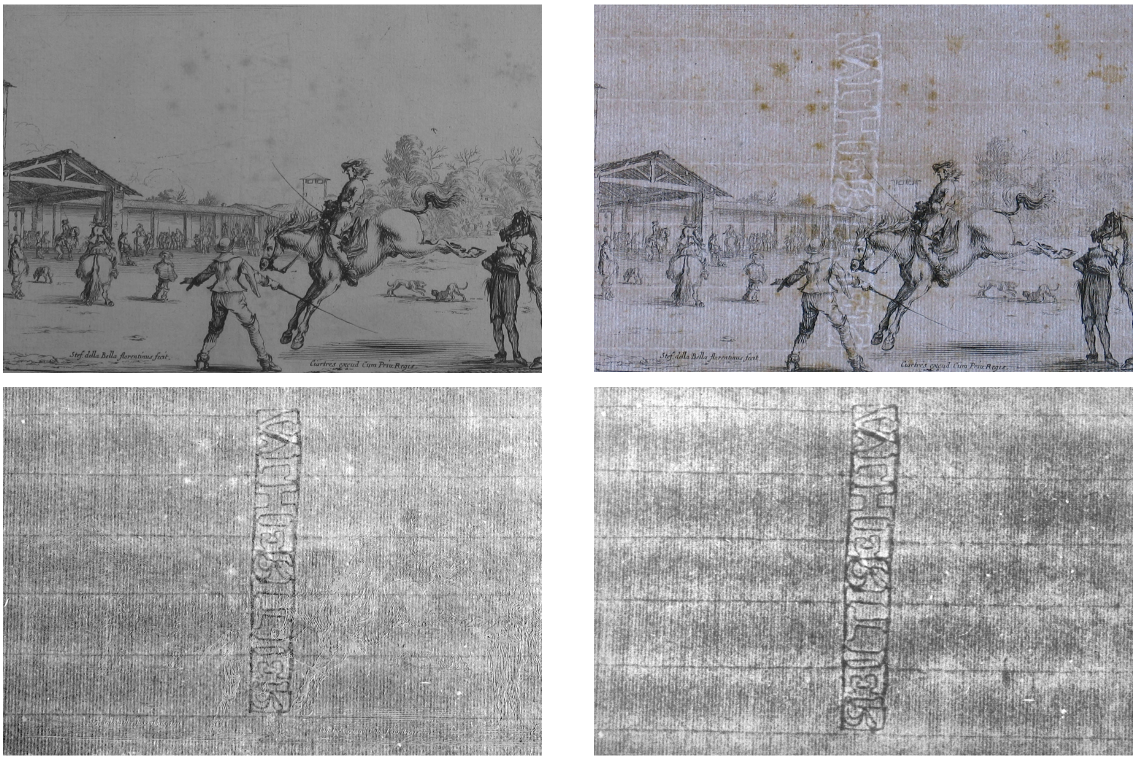

Figure 2. Reconstruction of the paper structure by means of backlight imaging; Picture of the print O (top-left); Picture of print plus paper structure B (top-right); reconstructed paper structure Y from O and B (bottom-left); The same paper structure generated by x-ray techniques (bottom-right).

A simple Matlab progam was developed that extracted the paper structure by performing the previously presented operations.

In figure 2 some results are presented for “Le Manege” by Stefano della Bella (1660-1664). As a matter of fact it is clear that the backlight method only works if the print itself is not too dark. It should be possible for the light to pass through the paper, e.g. most mezzotints are difficult for this technique. In the next sections the quality is discussed in more detail.

3. VISUAL COMPARISON FROM AN ART EXPERT POINT OF VIEW

Images of the paper structures are used for different purposes. Here the two imaging methods are compared for two applications. Art experts are asked whether the imaging method results in useful image. The first question was, whether the visible chain lines were useful for matching (i.e. identification of similar papers) and the second question was whether the watermark as visible could be used for watermarks catalogue generation. These questions were asked for a set of images of 7 papers. The results are presented in Table 1.

Table 1. Qualitative judgement (Good, Satisfactory, Unsatisfactory) of the two imaging methods for two applications.

Printed	Paper Structure	Print	Q1: matching		Q2: catalogue	
			X-ray	Backlight	X-ray	Backlight
Blanco	Clear	No	Good	Good	Good	Good
Blanco	Unclear	No	Good	Good	Good	Good
One-side	Clear	Light	Good	Good	Good	Good
One-side	Clear	Dark	Good	Unsatisfactory	Good	Unsatisfactory
One-side	Unclear	Light	Satisfactory	Satisfactory	Satisfactory	Satisfactory
One-side	Unclear	Dark	Satisfactory	Unsatisfactory	Satisfactory	Unsatisfactory
Double-side	Clear	Light	Good	Unsatisfactory	Good	Unsatisfactory
Double-side	Clear	Dark	Good	Unsatisfactory	Unsatisfactory	Unsatisfactory
Double-side	Unclear	Light	Satisfactory	Unsatisfactory	Satisfactory	Unsatisfactory
Double-side	Unclear	Dark	Satisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory

Two conclusions can be derived from this table. First of all the fact that it is mainly the print that determines whether backlight is a useful imaging method. For dark printed papers, backlight is not very useful, while for light prints the images generated by x-ray or backlight are somehow interchangeable. The second conclusion concerns the problems with the double-sided printed paper. It is very difficult for this type of paper to visualize the paper structure by backlight imaging. The main reason therefore is the fact that the front print and the back print are present in the backlight image and both should be subtracted from the backlight image in order to reconstruct the paper structure. More research is needed to develop a method that performs this task.

4. QUANTITATIVE COMPARISON

Also a quantitative comparison between x-ray and backlight imaging has been performed. The quality of the image Y is defined as contrast $c(Y)$, being the ratio between signal and noise. Where signal is in this case defined as the difference between the mean intensity of the (chain) line pattern, denoted by $\mu_{LP}(Y)$, and the background mean $\mu_{BG}(Y)$. And noise is the standard deviation of the noise in the image $\sigma_n(Y)$. So, the general definition of contrast is:

$$c(Y) = \frac{\mu_{LP}(Y) - \mu_{BG}(Y)}{\sigma_n(Y)}. \tag{3}$$

Main problem of using backlight imaging is the presence of the print in the backlight image. Therefore, the paper used for this comparison was blanco paper, such that the obtained result is the best quality that could be obtained with both imaging methods.

Before the contrast could be determined, two types distortions should be eliminated that distort the contrast measurements; the influence of the laid lines and variations in the background intensity. The laid lines hinder the determination of the local variance, while background variations cause difficulties in determination of the background mean. These distortions were eliminated by two methods, which are presented in [1] and result in the enhanced images $\hat{Y}$. The resulting enhanced x-ray or backlight image has a zero mean background intensity ($\mu_{BG}(\hat{Y}) = 0$) and a noise variance of one ($\sigma_n(\hat{Y}) = 1$). It is mentioned here that these enhancement methods are important for every system that processes watermark images.

Due to the enhancement steps the contrast becomes:

$$c\left(\hat{Y}\right) = \mu_{LP}\left(\hat{Y}\right). \tag{4}$$

This contrast is now measured on the basis of a chain line, because it is an approximately straight line. By means of the Radon Transform the intensity of a line is determined easily, because it computes the projection for a certain orientation θ_j. So, the average chain line intensity can be determined as a maximum of the Radon Transform. This intensity can be considered as the line pattern mean and thus the contrast becomes now:

$$c\left(\hat{Y}\right) = \mu_{LP}\left(\hat{Y}\right) = \max_j\left\{Radon\left(\hat{Y},\theta_j\right)\right\}. \tag{5}$$

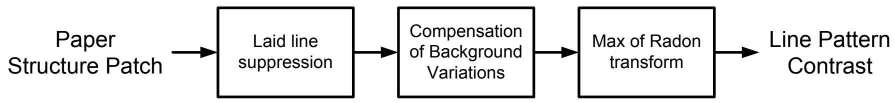

Figure 3. Process of measuring the image quality, represented by contrast.

The quality of the two imaging methods was compared for three pieces of paper. Corresponding regions were manually selected in the two reproductions of each piece of paper. For each piece of paper five regions were selected to obtain more reliable statistics. These regions contain all one chain line, for which the contrast was determined after enhancement. Figure 4 presents the contrast measures for the two methods as points. This experiment shows that on average the contrast of x-ray imaging is higher than the contrast from backlight imaging. Nevertheless, the contrast of backlight imaging shows to be about 80% of the x-ray contrast, which is an amount of contrast that would be enough for certain applications.

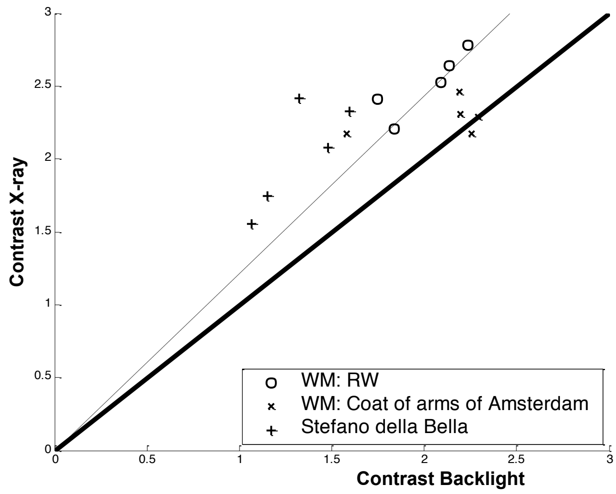

Figure 4. Contrast of backlight versus x-ray, for three different pieces of paper; The strong line represents the decision boundary whether x-ray has more contrast than backlight, and the dashed line represents the smallest squares fit to the contrast points.

5. CONCLUDING REMARKS

X-ray and backlight imaging are compared and x-ray clearly outperforms backlight. On the other hand, backlight is a promising technique for the reason of its simplicity. It is expected that both methods will be used by art experts in the near future. Therefore two important tasks can be addressed as future work. The first task is research on image processing methods for backlight imaging that improves the reconstruction of the paper structure by suppressing the print, especially for double-sided printed paper. The second task is the development of imaging methods to access heterogeneous databases, i.e. content based searching in databases containing images generated by both x-ray or backlight.

References

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[5] See e.g.: http://watermark.kb.nl, www.piccard-online.de and http://www.oeaw.ac.at/ksbm/wz/wzma2.htm