Scanners Test Report

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Abstract

For the digital restoration of a film the digitalization of it plays an important role. The color information present in the film and represented by the densities of the dyes must be transferred to the pixels of the scan preferably without loss. This report tries to understand how different scanners transfer this information for some film materials commonly used in the past.

1 Introduction

This report has been realized in the context of DIASTOR (`http://www.diastor.ch`), a research project for the digitalization and restoration of archival film. During this project different scanners have been tested on different types of film materials in order to understand how the scanners perform. The goal of this report is to study the features of the scanners and to help the restorers in the decision of which scanner to choose based on the film they have to restore.

Ideally a scanner should convert the dye densities present in the film into (r, g, b) values stored in the pixels of the scan without loss of information. The equation 1 from the paper [2] defines the relationship between the dye densities (c_1, c_2, c_3) and the (r, g, b) values:

$$\begin{pmatrix} r \\ g \\ b \end{pmatrix} = \int \begin{pmatrix} S_R(\lambda) \\ S_G(\lambda) \\ S_B(\lambda) \end{pmatrix} I_{in}(\lambda) 10^{-(c_1 b_1(\lambda) + c_2 b_2(\lambda) + c_3 b_3(\lambda))} \, d\lambda \tag{1}$$

In the equation 1, $I_{in}(\lambda)$ is the intensity of the scanner light at wavelength λ, (S_R, S_G, S_B) are the spectral sensitivity curves of the scanner sensors, and (b_1, b_2, b_3) are called the log-absorption-basis functions of the dyes, which describe how the dyes absorb the light. A possible analysis consists in understanding under which conditions the inversion of the equation 1 is possible. Unfortunately the equation 1 is based on physical properties of the film and the scanner that are not always available. For this reason we have decided to conduct other types of analyses.

There are two main categories of analysis that can be done on the scans. One is objective analysis and the other is subjective analysis. Objective analysis is based on measurements that can be done on the scans to be evaluated. Examples of objective analysis are histogram and Fourier analysis. Subjective analysis evaluates the scans based on the judgment of a group of subjects. Examples of subjective analysis are the rating study (where the subjects assign a score to each scan according to some criteria), the pairwise comparison study (where for each pairs of scan the subjects decide which is the best scan according to some criteria) and the verbose evaluation (written description of the features that a subject can notice in the scans). In this report we have combined objective and subjective analysis. More precisely, we have first conducted an histogram and a Fourier analysis, and then based on these analyses we have conducted some rating studies based on a single expert, and at the end a verbose evaluation of the scanner characteristics.

This report is based on scans that have been obtained by asking the scanner operators to adjust the calibration parameters of the scanners in order to obtain the best possible scans.

An important aspect of the analysis is that we didn't normalize the data, although not all the scans are gamma corrected or in the linear domain. Notice also that the scans don't have the same pixel resolution.

Another point to consider is the fact that we didn't scan all the film materials with all the scanners.

After this introduction there are two sections that present the scanners and the film materials. These two sections are then followed by the analysis section and the conclusion section.

2 Scanners

In this report we have analyzed 8 different scanners. The scanners are listed here:

- Altra 2K (website)
- Arriscan (website)
- D-Archiver (website)
- Director (website)
- Goldeneye (website)
- Kinetta (website)
- Northlight (website)
- Scanity (website)

3 Film Materials

This section presents the film materials that have been scanned. For more details about the film materials please refer to [3].

CRI

It is a stock that is used to make copies of a negative film. It is usually characterized by strong grain and contrast.

Dufaycolor

It is characterized by a mosaic or reseau of red filter strips separated by green and blue square filter patches, that when illuminated with white light and viewed from an appropriate distance, are fused in the eye of the observer to form a variety of hues.

Ektachrome

It is a multi-layered film characterized by red, green and blue sensitive layers.

Kodachrome

It is a color reversal film characterized by red, green and blue sensitive layers.

Technicolor

The Technicolor print is created from 3 matrices with cyan, magenta and yellow dye put into contact with a black-white film, so that the dyes are absorbed in the gelatin coating of the film (this process is called dye-transfer).

Film Tinting

The print based on film tinting is obtained by immersing a back-and-white film positive into a dye bath. The resulting print is monochromatic. The black areas remain black, while the clear areas are colored.

4 Analysis

In this section the analysis of the scanners is presented. For each film material we have taken a representative frame and then we have analyzed the scans of these frames.

In a first step we have computed the histograms and the Fourier transformations of the brightness image and the 3 color channels, and we have inserted them in the analysis sheets (see [1]). The analysis of this section is based on the evaluation of these sheets. Figure 1 is an example of an analysis sheet. In the analysis sheet there is the scanned frame, the histograms that have been normalized so that the area under the curve is equal to 1, the 2D Fourier transformations, and the 1D Fourier transformations obtained by averaging the 1D Fourier transformations of the rows and columns.

Each analysis sheet has been evaluated according to the following criteria:

- Color quality
- Global contrast

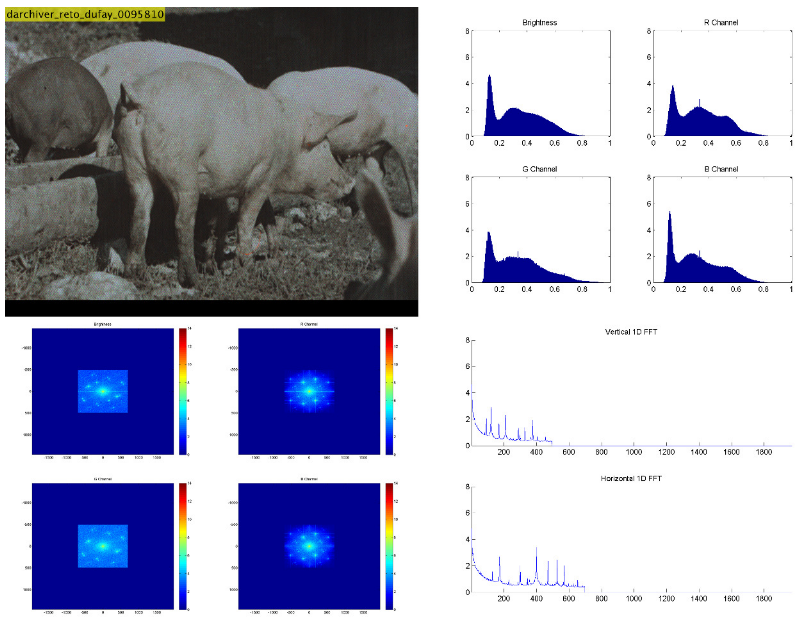


Figure 1: Example of analysis sheet.

- Local contrast
- Visibility of the grain
- Visibility of the Dufaycolor reseau
- Presence of narrow high peaks in the histogram
- Distribution of the energy in the Fourier transformation
- Presence of artifacts in the Fourier transformation

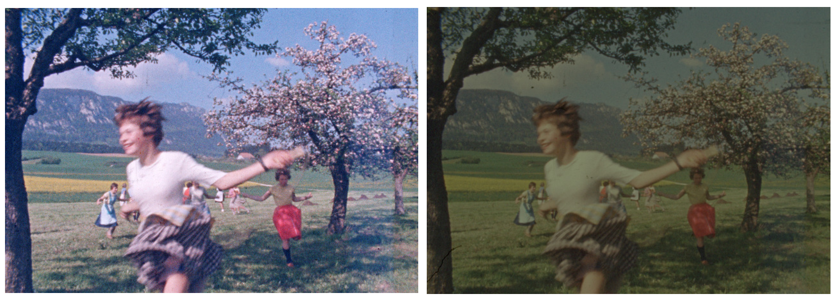
4.1 Color Quality

An important criteria to be evaluated is the color quality of the scans. This criteria is related to the saturation of the colors, the brightness, the presence of color cast, etc.. In the table 1 we have assigned to each scan a number from 0 to 5, where 0 means low quality and 5 high quality. The scores are subjective and based on a single expert. In the last column of the table there is the mean and the standard deviation of the scores for each scanner.

In the table 1 we haven't evaluated the Dufaycolor scans because of the difficulty of fusing the reseau patches while looking at the monitor of the computer. Regarding the scans of the Tinting frame we have evaluated them according to the quality of the monochromatism independently from the hue, since we don't know the original hue.

	CRI	Ektachrome	Kodachrome	Technicolor	Tinting	$\mu \pm \sigma$
Altra 2K	2	2	5	4		3.3 ± 1.5
Arriscan	3	5	3	0	1	2.4 ± 1.9
D-Archiver	2	2	1	4	4	2.6 ± 1.3
Director	3	1	3	1	5	2.6 ± 1.7
Goldeneye			1		1	1 ± 0
Kinetta	1	3	3	4	5	3.2 ± 1.5
Northlight	2	2	3	2	5	2.8 ± 1.3
Scanity	3	5	5	4	5	4.4 ± 0.9

Table 1: Color quality.



(a) Arriscan. (b) Northlight.

Figure 2: Comparison between the Arriscan and Northlight scans of the Ektachrome frame.

From the table 1 we can see that the scanner characterized by scans with an high color quality is Scanity.

In the Figure 2 there is a comparison between the Arriscan and Northlight scans of the Ektachrome frame.

4.2 Global Contrast

In this section we have analyzed the global contrast, which is related to the difference between the darkest and brightest element in the image. In the table 2 we have assigned to each scan a number from 0 to 5, where 0 means low contrast and 5 high contrast. The scores are subjective, based on a single expert, and obtained by looking at the scans and the histograms. In the last column of the table there is the mean and standard deviation of the scores for each scanner.

From table 2 we can see that the Altra 2K, D-Archiver, Northlight and Scanity scans have globally good global contrast. The worst scanners are Director and Goldeneye.

In the Figure 3 there is a comparison between the Altra 2K and Goldeneye scans of the Kodachrome frame.

	CRI	Dufaycolor	Ektachrome	Kodachrome	Technicolor	Tinting	$\mu \pm \sigma$
Altra 2K	3	5	2	5	3		3.6 ± 1.3
Arriscan	3	3	5	2	1	1	2.5 ± 1.5
D-Archiver	5	4	4	1	3	3	3.3 ± 1.4
Director	3	3	1	2	2	3	2.3 ± 0.8
Goldeneye				1		1	1 ± 0
Kinetta	2	2	4	3	3	4	3 ± 0.9
Northlight	2		3	4	4	3	3.2 ± 0.8
Scanity	3	2	4	4	4	4	3.5 ± 0.8

Table 2: Global contrast.

(a) Altra 2K. (b) Goldeneye.

Figure 3: Comparison between the Altra 2K and Goldeneye scans of the Kodachrome frame.

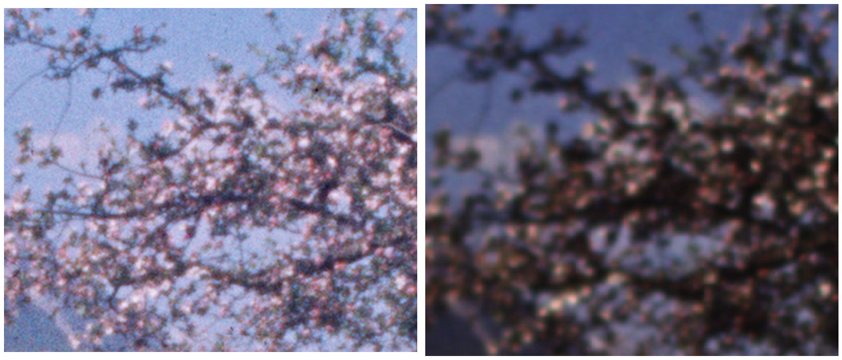
4.3 Local Contrast

Local contrast is another feature of the scans that we have analyzed. Local contrast is associated to the visibility of the small-scale details. In the table 3 each scan is assigned a number between 0 and 5, where 0 means low contrast and 5 high contrast. The scores in the table are subjective, based on a single expert, and obtained by looking at the scans. In the last column of the table there is the mean and standard deviation of the scores for each scanner.

	CRI	Dufaycolor	Ektachrome	Kodachrome	Technicolor	Tinting	$\mu \pm \sigma$
Altra 2K	2	0	2	3	3		2 ± 1.2
Arriscan	3	5	5	3	1	1	3 ± 1.8
D-Archiver	1	1	0	0	2	3	1.2 ± 1.2
Director	3	4	2	3	1	4	2.8 ± 1.2
Goldeneye				1		1	1 ± 0
Kinetta	2	0	1	2	2	3	1.7 ± 1
Northlight	3		2	3	3	4	3 ± 0.7
Scanity	3	4	4	4	4	4	3.8 ± 0.4

Table 3: Local contrast.

From table 3 we can see that the Scanity scans are characterized by good local contrast. Also Northlight have good scores. The worst scanners are D-



(a) Arriscan. (b) D-Archiver.

Figure 4: Comparison between the Arriscan and D-Archiver scans of a selected region of the Ektachrome frame.

Archiver and Goldeneye.

In Figure 4 there is a comparison between the Arriscan and D-Archiver scans of a selected region of the Ektachrome frame.

4.4 Visibility of the Grain

The visibility of the grain is another feature that we have considered. In the table 4 each scan is associated to a number between 0 and 5, where 0 means not visible and 5 means well visible. The scores in the table 4 are subjective, based on a single expert, and obtained by looking at the scans. In the last column of the table there is the mean and standard deviation of the scores for each scanner.

	CRI	Ektachrome	Kodachrome	Technicolor	Tinting	$\mu \pm \sigma$
Altra 2K	3	3	2	3		2.8 ± 0.5
Arriscan	5	5	5	2	2	3.8 ± 1.6
D-Archiver	2	0	1	3	1	1.4 ± 1.1
Director	4	4	4	5	4	4.2 ± 0.4
Goldeneye			4		2	3 ± 1.4
Kinetta	1	1	0	1	0	0.6 ± 0.5
Northlight	3	3	2	2	4	2.8 ± 0.8
Scanity	4	4	3	5	3	3.8 ± 0.8

Table 4: Visibility of the grain.

As can be seen in the table 4, the best scanners are Director and Scanity. The worst scanners are D-Archiver and Kinetta.

In Figure 5 there is a comparison between the Arriscan and Kinetta scans of a selected region of the CRI frame.

(a) Arriscan. (b) Kinetta.

Figure 5: Comparison between the Arriscan and Kinetta scans of a selected region of the CRI frame.

4.5 Visibility of the Dufaycolor Reseau

The visibility of the Dufaycolor reseau is presented by the table 5, where 0 means barely visible and 5 well visible. The values in the table 5 are subjective and based on a single expert.

Altra 2K	Arriscan	D-Archiver	Director	Goldeneye	Kinetta	Northlight	Scanity
0	5	1	4		0		4

Table 5: Visibility of the Dufaycolor reseau.

From the table it is possible to see that only in the scans of Arriscan, Director and Scanity the reseau is clearly visible.

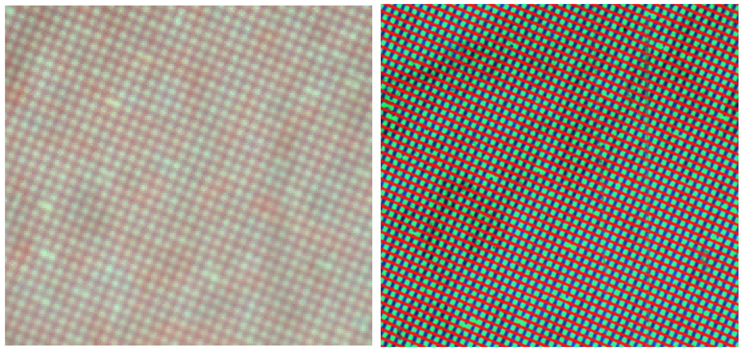
In Figure 6 there is a comparison of the Dufaycolor reseau of the Altra 2K and Arriscan scans.

4.6 Presence of Narrow High Peaks in the Histogram

The presence of narrow high peaks can point out a possible loss of sharpness. For example, if there is a narrow high peak in the dark region of the histogram, then probably the details in the shadows are not visible. In the table 6 the presence of narrow high peaks is indicated.

In the table some of the check marks are between brackets. It means that the operator scanned the film more than once with different calibration parameters, and not in all the scans there is a narrow high peak. Notice also that in the table there is CRI2 that represents a second CRI frame.

The presence of peaks in the scans of the CRI and CRI2 frames is caused by the frame content. From the table 6 we can notice that the Kinetta and Northlight scans are not characterized by narrow high peaks. This is not the case for the other scanners, in particular for D-Archiver.



(a) Altra 2K. (b) Arriscan.

Figure 6: Comparison of the Dufaycolor reseau of the Altra 2K and Arriscan scans.

	CRI	CRI2	Dufaycolor	Ektachrome	Kodachrome	Technicolor	Tinting
Altra 2K	✓	✓	✓		✓	✓	
Arriscan	✓	✓	✓	(✓)	✓	✓	✓
D-Archiver	✓	✓	✓	✓	✓	✓	✓
Director	✓	✓		✓	✓	✓	✓
Goldeneye					✓		✓
Kinetta	✓	✓					
Northlight	✓	✓					
Scanity	✓	✓				✓	(✓)

Table 6: Narrow high peaks in the histogram.

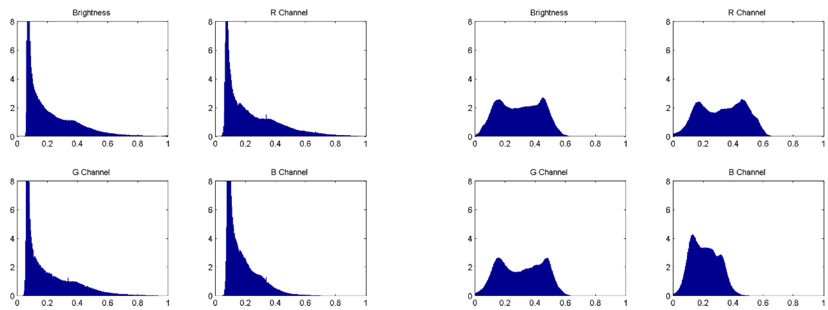
In Figure 7 there is a comparison between the histograms of the D-Archiver and Northlight scans of the Technicolor frame.

4.7 Distribution of the energy in the Fourier Transformation

The 2D Fourier transformation represents an image as a superposition of sinusoidal waves with different frequencies and directions. The Fourier transformation computes the amplitude and the phase of the sinusoidal waves, also called frequency components.

The Fourier plots in the analysis sheets are obtained by computing $log(1 + |FT|)$, where $|FT|$ is the amplitude of the sinusoidal wave. These plots are also called Fourier spectra. In the center of the spectra there is the zero frequency sinusoidal wave (constant image). Around the center there are the low frequency sinusoidal waves and far from the center there are the high frequency sinusoidal waves. The sinusoidal waves on a circle around the center have the same frequency but different directions.

Natural images are characterized by a spectrum with energy concentrated



(a) D-Archiver. (b) Northlight.

Figure 7: Comparison between the histograms of the D-Archiver and Northlight scans of the Technicolor frame.

in the center that continuously decreases by going far from the center.

The distribution of the energy in the Fourier transformation can be useful in order to understand which sinusoidal waves have been better captured by the scanner.

The Kinetta scanner is characterized by a particular energy distribution. Its spectra has a strange relatively high energy density along the axes far from the center, as can be seen in the Figure 8. This energy distribution is an evidence for structures similar to vertical and horizontal step edges, since step edges have a relatively high energy density also in the high frequency components.

Also some of the Arriscan scans have particular Fourier spectra, where the energy far from the center forms a square instead of a circle. An example of Fourier spectra of an Arriscan scan can be seen in the Figure 9.

The spectra of the Altra 2K and the D-Archiver scanners are characterized by a strange high energy at the ends of the axes especially visible in the R and B channels. In Figure 10 there is the spectra of the Altra 2K scan of the Ektachrome frame with the particular energy distribution.

In the Fourier transformation of the Dufaycolor scans it is interesting to notice the presence of peaks. These peaks are a clue for the presence in the scan of particular strong frequency components due to the Dufaycolor reseau. In the Figure 11 it is possible to see the particular spectra of the Arriscan scan of the Dufaycolor frame.

4.8 Presence of Artifacts in the Fourier Transformation

By looking at the Fourier transformation it is possible to notice some artifacts introduced by the scanners. In the table 7 the presence of the artifacts is indicated.

In the table some of the check marks are between brackets. It means that the operator scanned the film more than once with different calibration parameters,

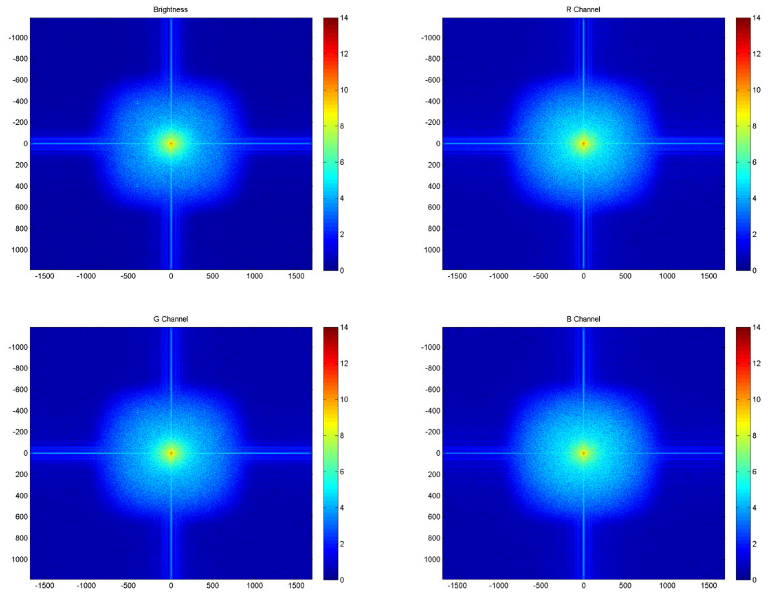


Figure 8: Fourier transformation of the Kinetta scan of the Kodachrome frame.

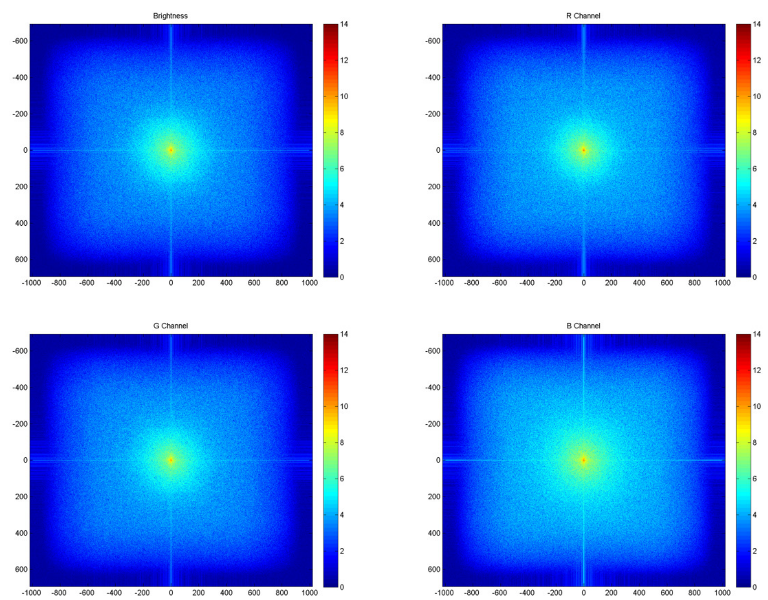


Figure 9: Fourier transformation of the Arriscan scan of the Ektachrome frame.

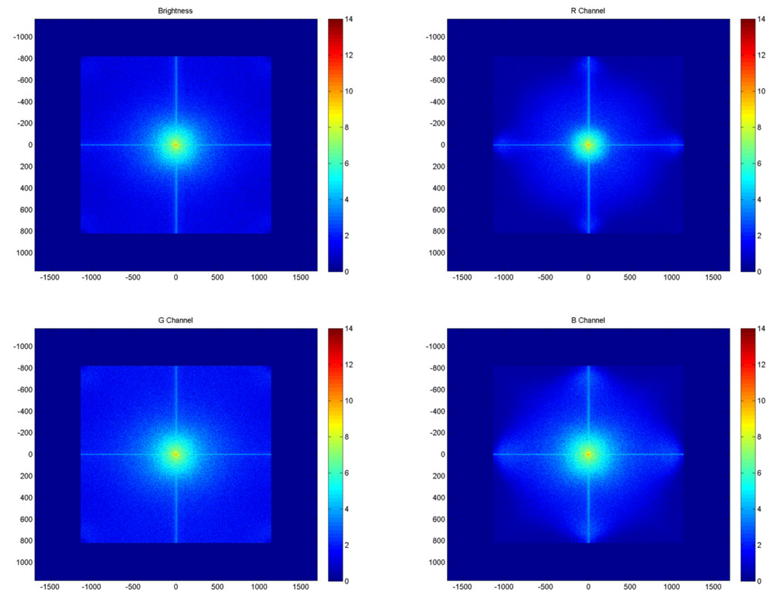


Figure 10: Fourier transformation of the Altra 2K scan of the Ektachrome frame.

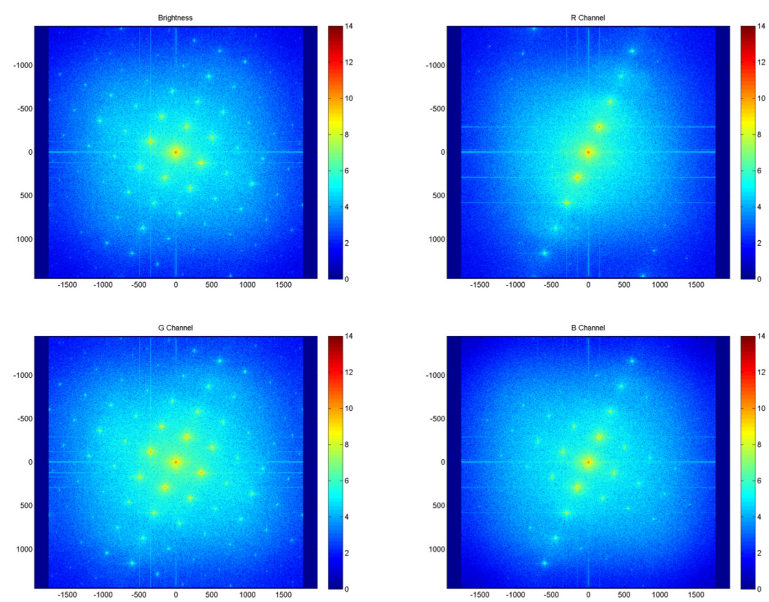


Figure 11: Fourier transformation of the Arriscan scan of the Dufaycolor frame.

	CRI	Dufaycolor	Ektachrome	Kodachrome	Technicolor	Tinting
Altra 2K						
Arriscan		(✓)		(✓)		
D-Archiver				✓	✓	✓
Director				(✓)		
Goldeneye				✓		
Kinetta						
Northlight	✓					
Scanity						

Table 7: Artifacts in the Fourier transformation.

and not in all the Fourier transformations of the scans there is an artifact.

The artifacts of D-Archiver consist in vertical lines not present in the other scanners. In spite of the presence of these artifacts in the Fourier transformation no artifacts are visible in the scans. In Figure 12 there is an example of the D-Archiver vertical lines present in the scan of the Kodachrome frame.

In the Fourier transformation of the Arriscan scan of the Dufaycolor frame there are strange circles as can be seen in the Figure 13. The circles are the evidence that some frequency components are missing, since in natural images the energy continuously decreases by going far from the center without strong oscillations.

The Fourier transformation of the Northlight scan of the CRI frame is characterized by oblique lines, especially visible the brightness image, and in the R and G channels. In Figure 14 these artifacts are visible.

Some of the Fourier transformations of the scans of the Kodachrome frame have an oblique line barely visible in the R channel (see Figure 15). This line is probably caused by the content of the frame.

The Fourier spectra of the Goldeneye scan of the Kodachrome frame has some strange points on the horizontal axis and some barely visible vertical lines especially strong in the B channel (see Figure 16).

5 Conclusion

In this report we have evaluated how 8 different scanners scan 6 different types of materials according to some criteria.

The Altra 2K scanner is characterized by scans with good color quality only for the Kodachrome and Technicolor frames. This scanner is globally characterized by good global contrast but not by very good local contrast. In its scans the grain is visible but the Dufaycolor reseau is barely visible. The Altra 2K Fourier transformations of the R and B channels have a strange high energy at the end of the axes. The Altra 2K Fourier transformations have no artifacts.

The Arriscan scans of all the frames except for the Technicolor and Tinting frames are characterized by good color quality, good global and local contrast, and by good visibility of the grain. The reseau of the Dufaycolor scans is

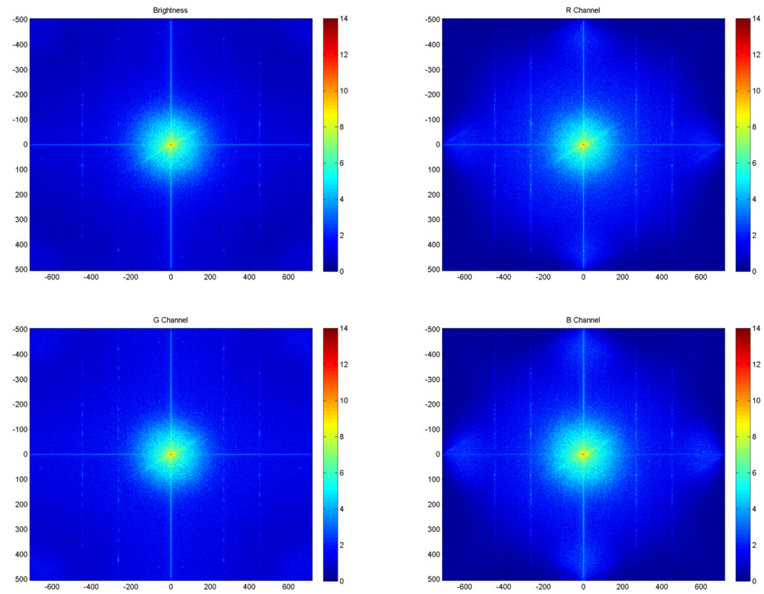


Figure 12: Vertical lines in the Fourier transformation of the D-Archiver scan of the Kodachrome frame.

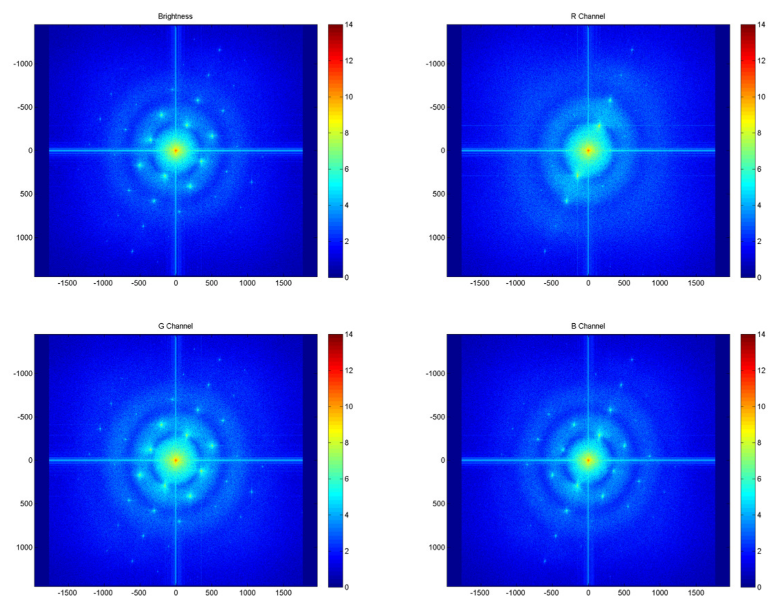


Figure 13: Circles in the Fourier transformation of the Arriscan scan of the Dufaycolor frame.

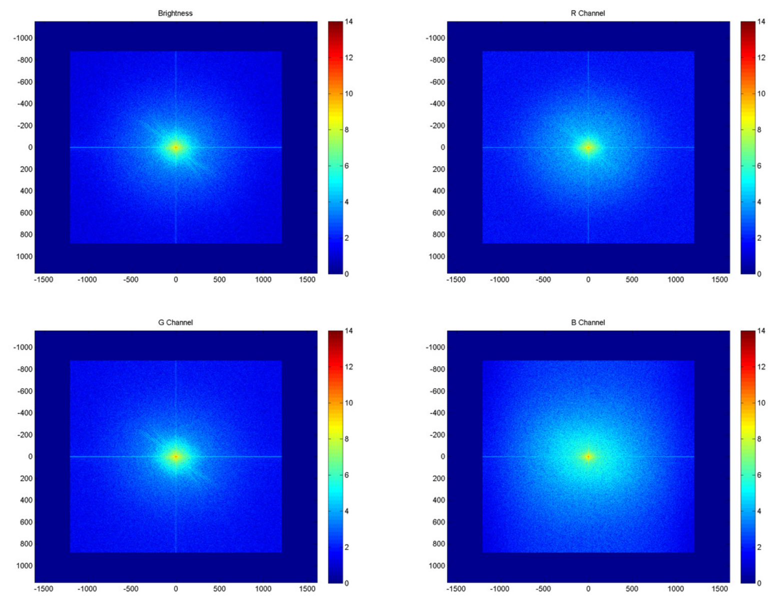


Figure 14: Fourier transformation of the Northlight scan of the CRI frame with oblique lines.

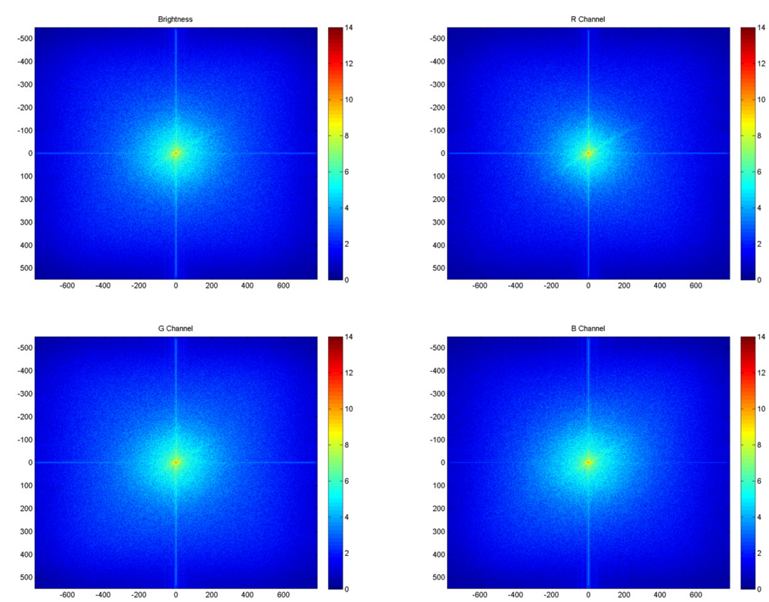


Figure 15: Fourier transformation of the Director scan of the Kodachome frame with an oblique line especially visible in the R channel.

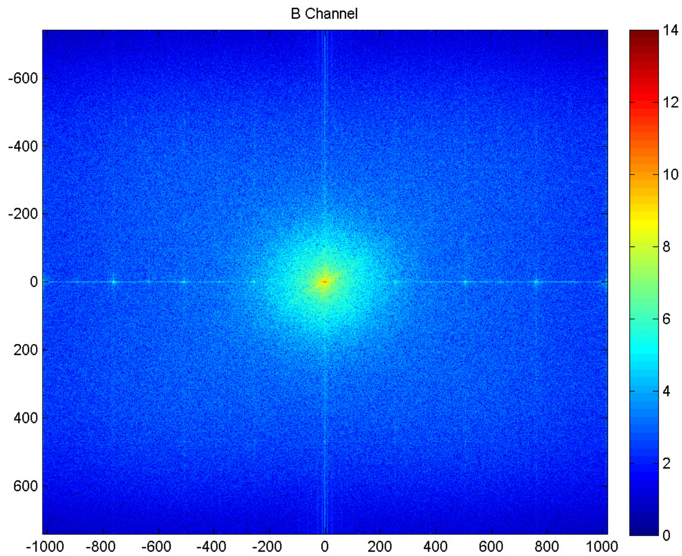


Figure 16: Fourier transformation of the Goldeneye scan of the Kodachrome frame.

clearly visible. The Arriscan Fourier transformations have a recognizable energy distribution (see Figure 9). Some of them are characterized by artifacts, the most important one are some strange circles in one of the scans of the Dufaycolor frame (see Figure 13).

Only the D-Archiver scans of the Technicolor and Tinting frames have good color quality. The D-Archiver scans are characterized by good global contrast except for only the scan of the Kodachrome frame. The local contrast of D-Archvier is globally rather low and also the visibility of the grain and the Dufaycolor reseau is mostly bad. The D-Archvier Fourier transformations of the R and B channels have a strange high energy at the end of the exes. Most of D-Archiver Fourier transformations are characterized by strange vertical lines (see Figure 12).

The color quality of only the Director scans of the CRI, Kodachrome and Tinting frames is good. The Director scans of the CRI, Dufaycolor and Tinting frames have a decent global and local contrast. The grain and the Dufaycolor reseau in the Director scans are clearly visible. The Fourier transformations of the Director scans have no artifacts, except for one scan of the Kodachrome frame.

The Goldeneye scanner has been tested only on the Kodachrome and the Tinting film materials. Its scores are globally quite low.

The Kinetta scans have good color quality except for the scan of the CRI frame. The Kinetta scanner is characterized by a moderately good global contrast except for the scans of the CRI and Dufaycolor frames. The local contrast of the Kinetta scans is globally low, and the grain and the Dufaycolor reseau in the Kinetta scans are barely visible. The Kinetta Fourier transformations are characterized by relatively high energy density along the axes far from the center (see Figure 8), but they have no artifacts.

The color quality of only the Northlight scans of the Kodachrome and Tinting frames is good. The Northlight scans are globally characterized by acceptable global and local contrast. Except for the scans of the Kodachrome and Technicolor frames in the Northlight scans the grain is clearly visible. Only the scan of the CRI frame is characterized by an artifact in the Fourier transformation.

From the data that we have analyzed, the scanner that performs better is Scanity. This scanner is characterized by good color quality, good global and local contrast and also by good visibility of the grain and the Dufaycolor reseau. In its Fourier transformations the artifacts are absent.

By looking at the analysis section of this report we can recommend for each film material which scanners are more suitable. We have decided that a scanner is suitable for a given film material if all the scores in the tables of color quality, global contrast, local contrast, visibility of the grain and the Dufaycolor reseau are at least 3. In the following list for each film material there is a list of scanners that can be used. In the brackets there is the global score obtained by averaging the scores of color quality, local contrast, global contrast and visibility of the grain and Dufaycolor reseau.

- **CRI**: Arriscan (3.5), Director (3.3), Scanity (3.3)
- **Dufaycolor**: Arriscan (4.3), Director (3.7)
- **Ektachrome**: Arriscan (5), Scanity (4.3)
- **Kodachrome**: Scanity (4)
- **Technicolor**: Altra 2K (3.3), Scanity (4.3)
- **Tinting**: Director (4), Northlight (4), Scanity (4)

As previously mentioned this report is based on scans obtained by asking the scanner operators to choose the scanner parameters in order to obtain the best possible scans. It is clear that different scanner parameters can result in completely different scans and that the scans are highly dependent on the skills of the operator. This is one limit of the report. Another limit is that the scores of the tables in the analysis section are subjective and based on a single expert. Other experts could assign different scores.

References

[1] Simone Croci, Tunc Aydin, and Aljoscha Smolic. *Analysis Sheets*. URL: `https://graphics.ethz.ch/Downloads/Publications/Tech_Reports/2015/Cro15b/ScannerTestReport.zip`.

[2] Alan Edelman, Frank Wang, and Arun Rao. "A Physically Based Numerical Color Calibration Algorithm for Film". In: (2003).

[3] Barbara Flueckiger. *Timeline of Historical Film Colors*. URL: `http://zauberklang.ch/filmcolors/`.