What if the image quality analysis rates my digitization system a "no go"?

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Abstract

As solutions for quality assurance (QA) like UTT[1] (Universal Test Target) and 'golden thread'[2] have been introduced it is now easy to monitor the quality of a digitization system. But several questions remain that have not yet been answered. Among these the following three are the most important ones:

1. How do I calibrate the system step by step to meet given specifications like e.g. Metamorfoze?
2. Are the existing specifications suitable for my individual application?
3. What do I do if one of the image quality aspects is out of the range?

This paper tries to answer these questions and to provide guidance for the daily use of the QA solutions.

The calibration process

We can expect several scanner and camera manufacturers to integrate an automated quality assurance system into their future digitization solutions. These systems will perform a calibration based on test targets like the UTT. For those who to not have such an automated solution a manual calibration and quality control is also possible but depending on the individual soft- and hardware solution it may be time consuming.
For the calibration the user is often tied to the tools the manufacturer provides. Since these tools can vary in quality it is an aspect the user needs to have in mind when buying a device. Due to the variety of tools this paper can only mention the different steps the calibration process has to go through and some typical well known tools. Although the first couple of steps may be well known and obvious they are mentioned to deliver a complete picture of the process.
Let's look at this process step by step.

Room setup

Make sure that the walls and objects surrounding the reprographic system are painted in neutral colors. Avoid stray light from reflections of the illumination used for digitization as well as light coming in from other sources like daylight and ambient light.
Make sure that the floor is made of solid material and that the room temperature is kept constant over time. Ideally a temperature of 22°C ±2° should be selected if the originals do not require a different temperature for preservation reasons.

Stable repro stand

Make sure that the stand that you use for the scanner or camera system is stable and does not move especially during the exposure since this will result in motion blur and therefore in a decreased resolution.

Select appropriate Illumination, camera, lens, scanner that fulfills the requirements

Based on the requirements for the image quality of the digital image the correct equipment has to be used. Many systems use fluorescent daylight tubes as illumination source. These tubes are efficient, stable over a long period of time, and provide the right color temperature. They can be used to uniformly illuminate large areas. Depending on the type of original the spiky spectral distribution of the tubes may cause some reproduction problems - known under the term of metamerism - for specific colorants. The required level of detail, and the size of the originals influence the selection of the camera lens combination. For a turnkey scanning solution the system needs to be checked for its capabilities to fulfill the requirements. Do not trust the spec sheet provided by the manufacturer since these sheets e.g. mix the sampling rate with the resolution and often provide dynamic ranges that the system cannot really reproduce. You can use a quality control system like 'golden thread' or 'UTT' to find out about the real image quality measured according to existing standards like ISO 21550[3] for Dynamic range or ISO 16067[4] for resolution.

Scale and focus adjustment

The next step is that the system has to be set up in a way that the original is not cropped and the required sampling rate (number of pixels per inch) is reached. For a scanning system this step is usually performed by selection of the size and type of original. A camera system may need to be adjusted in object distance and sampling rate. Both types of systems may require a focus adjustment to reach the required level of detail and keep in mind that lenses do not deliver the best performance when operated at open aperture. F-Stops between 5.6 and 11 are often used for best lens performance.

Illumination adjustment

The illumination needs to be adjusted in a way that no specular highlights appear on the image of the original and it should be uniform over the entire original. The uniformity can be checked by using an illuminance meter. The measured non uniformity should be less than 30% (1/3rd f-stop) to reach good results. For Originals smaller than A1 the non uniformity for excellent results should be lower than 10%.

Exposure setting (Aperture and ISO speed)

With the aperture adjusted to the right stop the exposure time needs to be set to a value that no part of the image is in saturation (reaches the maximum digital output value). For a precise adjustment the easiest way is to use a grayscale and make sure that the brightest patch reaches the desired digital output value. Overexposure needs to be avoided!!! Details in the highlights that are clipped cannot be restored using image processing. Set the camera to the lowest ISO speed possible to minimize the amount of temporally varying noise in the image

Signal dependent fixed Pattern Noise (PRNU)

Scanners usually use a white reference target or an invisible strip inside the cover to calibrate exposure, reduce illuminance dependent non-uniformity, and to eliminate existing photo response non-uniformity (PRNU) of the sensor. Some camera software allows the same kind of thing with camera Systems as well. In this case the user needs to follow the instructions provided by the manufacturer.

Software settings

Check all software settings to make sure that e.g. no sharpening is used, the scaling is set to the right level, illumination warm up times are ensured and for all other necessary aspects that depend on your individual system.

Color Profile

Make sure that your system supports ICC color management. If not you are completely dependent on the color processing provided by the device. Please note that an ICC color profile affects not only the color reproduction but also the tonal curve. Make sure that you use the right profile for the type of original that you are scanning. If necessary you may want to create an individual profile for your device-original combination. In that case you need a test chart for profiling (like an IT8 or a Color Checker SG) and if possible this chart should be on the same material and using the same colorants as the original that you will scan with that profile. Scan the target with all color and tonal adjustments switched off and no profile selected in the software. Let's name that image a raw image. In addition you will need software to create the new profile from the raw image in combination with the reference values provided with the target. Place that profile in the folder specified by the manufacturer and select it in you scanning application. You will see that the colors and tones will change. Some manufacturers provide test charts and profiling software together with their devices.

Color encoding (space) setting

In the software you have to select your output color encoding which usually is one of the following: sRGB, Adobe RGB, eciRGBv2, or ProPhoto RGB. There are a few other color encodings that can be found but they do not play an important role. The correct term is color encoding because to specify the color in an image file it takes more than just the description of the 3 dimensional color space (see ISO 22028-1[5] for details).

Tonal correction

To get the tone reproduction right you can use a grey scale. For each of the grey patches the reference RGB values for your selected RGB encoding should be provided with the scale. They need to be compared to the one your scanner produces. Try to match these reference values as good as possible.

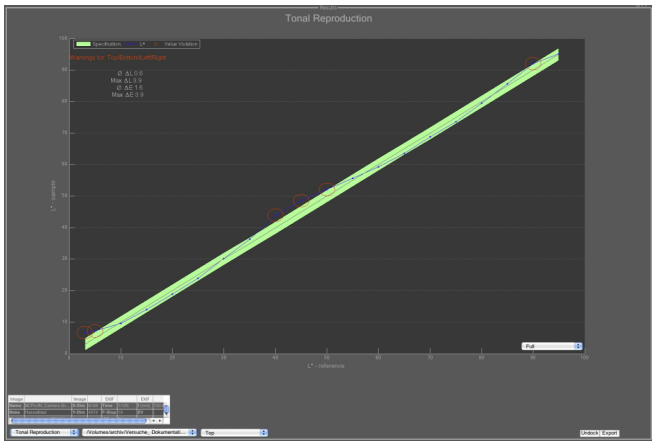

Figure 1: *Input versus output L* value. Ideally the curve should be within the green tolerance range.*

White balancing

With the right color profile the white balance should already be ok. If it is not you may need to set it by using the specified tool in your software and clicking on a grey patch of a grey scale that you place on the scanner.

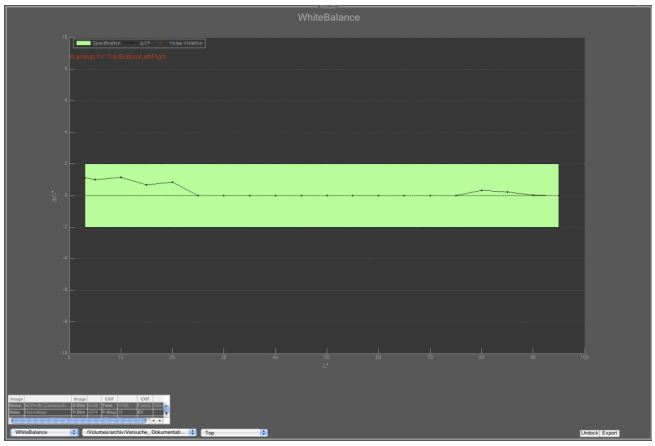

Figure 2: *The neutrals should be in the green range around the C* value of 0.*

Color correction

With the ICC profile and the tonal correction in place this aspect should be obsolete. Only if you system does not support ICC color management or you do not have the right profile for the material of your original you may need to perform additional color corrections depending on the tools provided by the scanning software.

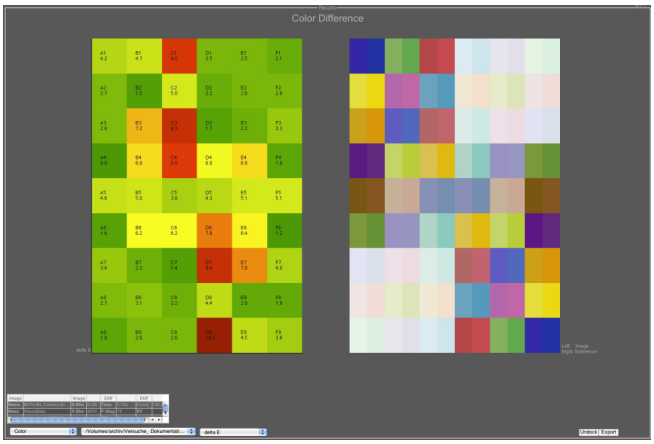

Figure 3: *The distance between the original colors and the colors produced by the scanning system indicates the color reproduction quality.*

Rescaling

In case you are using a turnkey solution scanning system the size in the digital image should match that of the original meaning that a certain distance in the original is represented by the same distance in the digital file and the sampling rate in pixels per inch is set to the appropriate value.

In case you are using a camera the sampling rate is usually set to a fixed value like 72 or 300 pixels per inch and the amount of rows and columns depending on the specs of the imager. This is output related and does not depend on the size of your original because the camera does not know the scaling factor. Depending on the size of the original and focal length you may need to rescale the image.

Quality control

After all these calibration steps you should perform a quality check by using one of the existing test charts (like "golden thread" or "UTT"). Scan one of these charts and evaluate all significant image quality aspects using software that support this type of chart. That way you know that all steps were successful and that you get the desired quality.

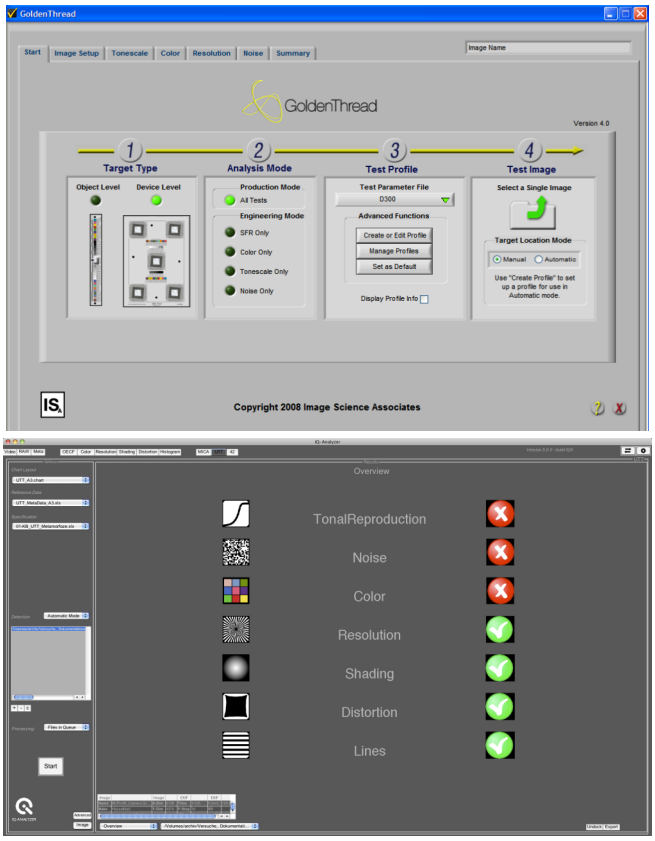

Figure 4: *Currently there are two independent image quality control systems on the market. The UTT and the Golden Thread.*

The right Specs

In many cases the aim of digitizing cultural heritage and documents is to receive an exact replica of the original.

All of the existing image quality specifications like "Metamorfoze"[6] and "Federal Technical Guidelines for Digitizing Cultural Heritage Materials"[7] are specified for this purpose. Even if an image of an original is created for other purposes like publication in a catalogue or creating a poster the starting point usually is the replica of the original. From this 'digital original' the other images can be created using contrast, tonal, color, and sharpness enhancement.

The specifications are designed to make sure that your image quality is excellent and that your reproduction is as close to the original as possible. So if you are able to meet the tolerances in these specs you can be sure that your reproduction is pretty good.

Problem with current Specifications

But there is the problem with the lag of practical experience with both of the two mentioned specifications.

The current general feedback received from users who try to meet the Metamorfoze specs is that the tolerances are so tight than not a single system has been found so far that meets all the specifications.

The "Federal Technical Guidelines for Digitizing Cultural Heritage Materials" defines thresholds for tonal response curve, white balancing and Noise in digital values. This may work for white balancing because the color encodings are all designed in a way that equal values for RGB result in neutral grays. For the tonal response curve and noise equal variations in digital RGB values over the tonal range are perceptually not uniform. For example a variation in digital values in mid grey areas is more visible than the same variation in dark greys[8,9]. This means the specified tolerances result in perceptually different thresholds.

Both the Metamorfoze Guidelines and the Federal Technical Guidelines define various tolerance levels depending on the applications. This makes sense because e.g. a digitization for character recognition does usually not have high requirements on the accuracy of color reproduction. The Metamorfoze guidelines define the applications with the related tolerances. The Federal Technical Guidelines are more flexible and define a star rating system for each image quality aspect and the requirements are defined by the project itself.

Although it seems to be difficult or maybe impossible to reach the Metamorfoze guidelines and also to reach the highest star ratings of the Federal Technical Guidelines it makes sense to get as close as possible to the aim values defined by the specifications. So every digitization project should try to follow the principle of the guidelines. It will take a couple of more years and experience with the methods to modify the guidelines in a way that they become a practical toolkit for image quality assurance.

In the meantime the difficulty will be to rate the acceptability of the values that are out of the specs. Here is what you can do if some of the values are out of the specifications or you only reach a low star rating. Follow the list step by step:

1. If a value is within the specs you can rely on the result and do not have to worry about this aspect.

2. For a value that is out of specs you should check if the calibration for this aspect has been performed correctly. If that is not the case redo the calibration and check the result again.

3. If the calibration is ok and the value is still out of specs review the possible reasons from the following catalogue. If none of the reasons mentioned is responsible for the deviation the reason will be a device dependent characteristic.

4. In this case a decision has to be made if the characteristic is acceptable for the project or not. If it is not you have to select a different device for the digitization.

Catalogue of things that can go wrong

The following catalogue provides a list of potential reasons if problems occur with one of the image quality aspects. The items are sorted by image quality aspect and numbered for identification and communication purposes.

Reasons for a scanner running out of specs?

Tonal curve

Problems that can occur with tone reproduction:

1. inefficient sensor
2. under- / over exposed picture (results in an overall shifting of the curve)
3. illumination
4. application of a wrong gamma / tonal curve
5. auto-contrast failure
6. inappropriate black / white point calibration
7. strong deviation of single values (need to check, if reference data is correct and if these reference data corresponds to preferences or maybe problem with tonal curve)
8. scattered light due to reflections / wrong illumination of the test target
9. scattered light due to a dirty mirror, etc. in the device

White balance

Possible reasons for an incorrect white balance:

10. wrong / or non perfect auto white balance
11. wrong / or non perfect manual white balance
12. bad black / white point setting
13. illumination does not match the adjusted white balance
14. strongly colored environmental surround
15. wrong reference data of the test target

Noise, standard deviation

Possible reasons for a too high noise level:

16. high sensitivity selection in the camera (ISO speed)
17. under exposed picture, that was brightened by a tone curve adjustment (Aggressive digital signal amplification)
18. to high standard deviation / noise in the color patches of the test target
19. poor sensor calibration (fixed pattern noise)
20. temperature to high
21. underexposure due to wrong camera adjustments / wrong illumination adjustments
22. dust and dirt on the sensor or the chart

Signal to noise ratio, gain modulation

Possible reasons for a low signal to noise ratio:

23. same reasons as for noise with inclusion of a wrong / varying incremental gain of the signal
24. wrong tonal curve adjustment

Color reproduction

Possible reasons for wrong colors:

25. incorrect color profile or color correction matrix for the type of original or type of illumination
26. inaccurate color processing in the camera software leading to the question if device is capable to scan the original within specs
27. change in illumination, old or defect illumination components
28. under- or overexposed image
29. wrong software settings (saturation boost etc.)
30. strongly colored environmental surround

possible solution:
check ΔE, ΔL, ΔC, ΔH to find out about the source of the problem

Resolution

Possible reasons for wrong sampling rate:

31. poor calibration of scanner or wrong scale adjustment of camera
32. wrong units at calibration
33. incorrect scanner / camera settings

Possible reasons for a low MTF 10 frequency (resolution):

34. wrong sensor-lens-configuration
35. focus problem (picture is out of focus)
36. for scanners: inaccurate adjustment of the lens or a mirror (results in non uniform sharpness over the scanned area)
37. lag of sharpness due to diffraction (particularly for small sensors)
38. poor optics
39. poor choice of aperture stop
40. mechanical vibrations
41. too aggressive noise control

Possible reasons for differences in the horizontal and vertical MTF 10 value:

42. camera internal differences in the image processing for different directions
43. resolution limits in one direction because of lens errors such as astigmatism
44. for scanners: different resolutions in slow and fast scan mode due to Sensor geometry (e.g. 2 linear lines shifted by half a pixel)
45. transport mechanism of scan head defect or inaccurate
46. lens is too good / bad in one direction

Possible reasons for variations of MTF 50 frequency (sharpness):

47. sharpening (raises MTF)
48. inappropriate / bad lens
49. certain noise reduction algorithms in the image processing
50. scattered light due to a dirty / scratched lens
51. scattered light due to specular highlights / wrong illumination adjustments

Distortion

Possible reasons for distortion:

52. lens problem
53. for scanners: mechanical problems (problem with continuous movement which results in different distances in squared pattern)
54. mismatched sampling rate for horizontal and vertical direction

Shading

Possible reasons for loss of light in the corners:

55. photometric shading (cosine law)
56. vignetting of the lens
57. vignetting of objects in the optical path such as a baffle.

Banding and line defects

Possible reasons for stripes in the pictures:

58. defect scan line / pixel
59. power supply or other electronic component is defect or influences the signal processing
60. dust and dirt on the sensor or the chart

References

[1] Universal Test Target, http://www.universaltesttarget.com/, evaluation tool http://www.image-engineering.de
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[3] ISO 21550, scanner dynamic range
[4] ISO 16067, scanner resolution
[5] ISO 22028-1, color encoding
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[7] Federal Agencies Digitization Guidelines Initiative (FADGI), Technical Guidelines for Digitizing Cultural Heritage Materials, http://www.digitizationguidelines.gov/guidelines/digitize-technical.html
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[9] The Perception of noise depending on spatial frequency and contrast with the aid of the CIE- Lab colorspace, Nicole Kidawa, Christina Simon, diploma thesis, University of applied sciences, Cologne

Author Biography

Dietmar Wueller studied photographic sciences from 1987 to 1992 at the University of Applied Sciences Cologne (Germany). Since 1997 Dietmar Wueller runs an independent test lab for digital cameras and scanners that has also developed to one of the leading suppliers for test equipment for digital image capture devices. He became the German representative for ISO TC42 WG18 in summer 2000, is a member of the board of the European Color Initiative, and besides running his company he is a publicly certified expert on digital photography and scanning.