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Author(s):

Neumann, Klaus; Baltsavias, Emmanuel P.

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ENHANCEMENT OF THE RADIOMETRIC IMAGE QUALITY OF PHOTOGRAMMETRIC SCANNERS

Klaus NEUMANN*, Emmanuel BALTSAVIAS**

*Z/I Imaging GmbH, Oberkochen, Germany
neumann@ziimaging.de

** Institute of Geodesy and Photogrammetry, ETH Zurich, Switzerland
manos@geod.baug.ethz.ch

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ABSTRACT

Photogrammetric scanners are used more and more for the digitization of aerial images. Geometric accuracy has always played an important role in photogrammetry, while aspects of the radiometric quality have been somehow underestimated. However, radiometric problems may cause geometric artefacts, lead to loss of film information, color shifts and noise, and influence the increasingly used subsequent automated image processing (matching, feature extraction etc.). This paper deals with investigations and methods to enhance the radiometric quality of the scanner output. The work presented refers to the Z/I Imaging PhotoScan, but the analysis and methods are applicable to other scanners and CCD-based sensors. The investigations were carried out by modifying a scanner at Z/I Imaging, Oberkochen, Germany, use of appropriate test patterns and analysis software. Proposals on improving the radiometric quality of the scanner will aim at making as little modifications to the existing hardware as possible, trying to implement most of them in software.

1 INTRODUCTION

This study is focused on the radiometric quality of photogrammetric scanners. The results will be used to enhance future hardware and software products, and to speed-up or automate processes and setting of scanner parameters. The tests performed for this purpose involved not only the scanner hardware and software, but also the influence of film exposure and film processing on the quality of the scanner output.

Digital image generation is a dynamic process, which is affected by a large variety of factors such as the film type, weather, film exposure, film processing and the scanner used. The better these factors are matched to each other, the higher the quality of the final product will be.

All analysis conducted in this context was based on results obtained with the PhotoScan high-performance photogrammetric scanner from Z/I Imaging (Fig. 1 and for a description see Mehlo, 1995; Roth, 1996). All tests were run with a scanner in Oberkochen, Germany. The software packages Phodis SC and PhotoScan were used for the scans, Adobe PhotoShop and Microsoft Excel for the evaluation.



Figure 1. PhotoScan photogrammetric rollfilm scanner.

2 LINEARITY AND INFLUENCE OF INTEGRATION TIME, COLOR BALANCE

The sensor is an RGB tri-linear CCD sensor from Kodak with the type designation KLI-10203. Due to the design of the objective lens, only 5632 of the 10200 active pixels are used per color channel. The pixels have a physical size of $7\mu\text{m} \times 7\mu\text{m}$. The optical system is of the 1:1 mirror optics type. This provides scan swaths with a nominal width of $39424\mu\text{m}$. The software permits direct setting of the integration time in steps of 0.1 ms. The integration time is adjustable within a range from 0.1 ms to 25.5 ms. All the tests were conducted without a lookup table, i.e. a 1:1 lookup table was used for the scans. The A/D converters used with the CCD camera have a 10-bit resolution, the data output format is 8 bit-per pixel (24-bit for RGB).

The first test pattern was a calibrated gray scale on film from Kodak, called photographic step tablet No. 3, with 21 densities from 0-3 oD (oD ...optical density) in steps of 0.15 oD. The scan pixel size was $7\mu\text{m}$. Only the central part of each gray scale was used for the analysis.

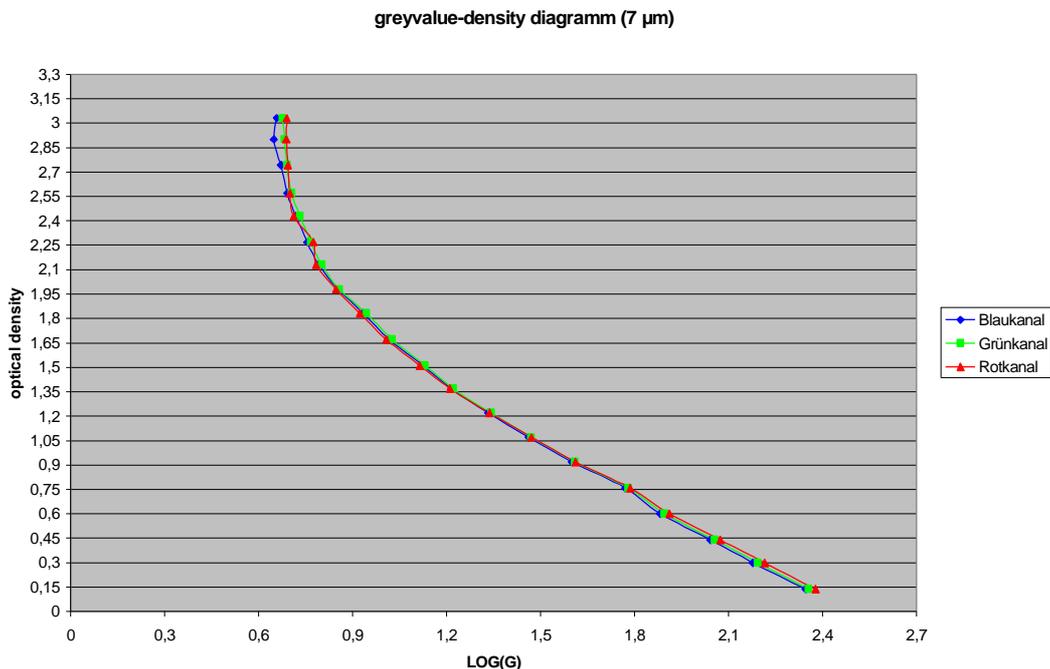


Figure 2. Linearity of the CCD sensor.

As it can be seen in Fig. 2, a linear behavior of the scanner can be assumed for a density range from 0 to 2.1 oD, while the behaviour of the three spectral channels is very similar. With high optical densities (> 2.1 oD), the behavior becomes non-linear and the densities can be hardly separated from the neighbouring ones. This fact has to be taken into account in the computation of the lookup table and integration time. The integration time will be optimized for the minimum density value of the aerial image (brightest part).

A further test provided a gray level/integration time diagram showing the mean values of the gray levels over an integration time interval of 0.1 ms to 3 ms. The test pattern was a homogeneous gray glass plate with a density of 0.3171 oD. The scan pixel size was $7\mu\text{m}$.

The results seen in Fig. 2 can be described as $\log(G) = f(\text{oD})$
 The results seen in Fig. 3 can be described as $G = f(\text{integration time})$

where G is the greyvalue.

As Fig. 3 shows, again the three spectral channels have similar behaviour, while the gray level intensity increases linearly with integration time.

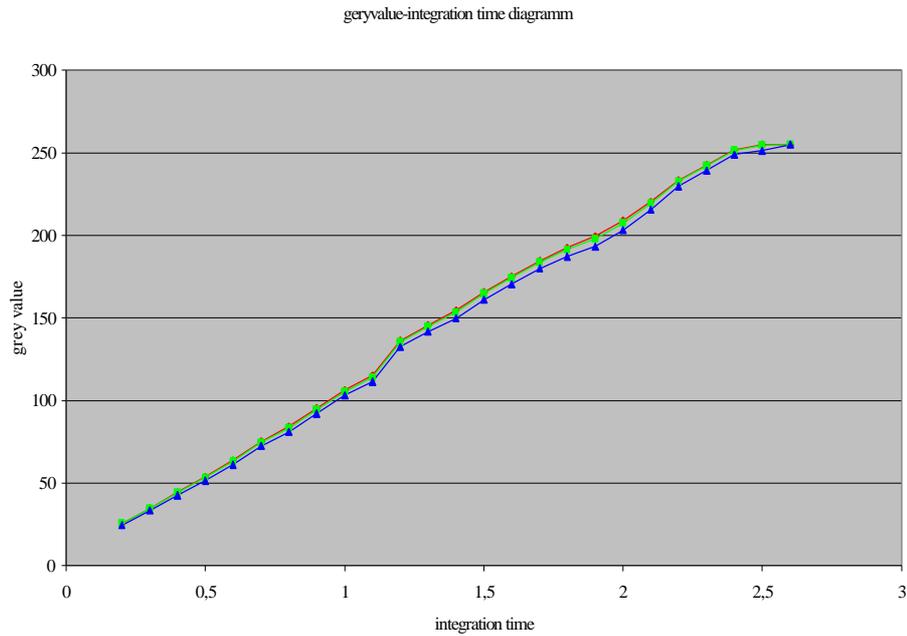


Figure 3. Grey level variation as a function of integration time.

To ensure that the characteristics of all three color channels are in coincidence, the different sensitivities of the CCD lines have to be matched to each other. Correct adjustment of the color balance is of decisive importance for the true-to-color rendition of the film to be scanned. An example of a poorly adjusted system can be seen in Fig. 4.

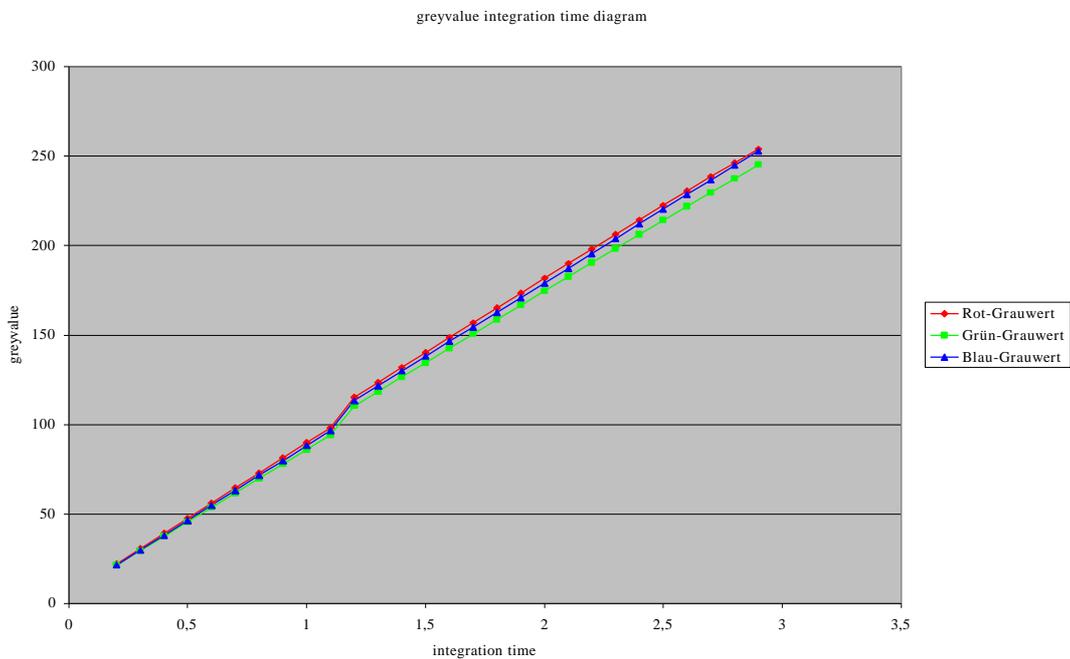


Figure 4. Poorly adjusted color balance of CCD sensor.

It is evident how the sensitivity of the green channel deviates from that of the red and blue channels. This may lead to color shifts. Although such color shifts can be corrected via lookup tables, this requires additional time in practical work and manual intervention.

3 NOISE BEHAVIOR AND INFLUENCE OF INTEGRATION TIME AND ILLUMINATION

To investigate the noise behavior, several homogeneous gray glass plates with different optical densities were scanned. The advantage of glass-based over film-based gray scales lies in the absence of noise caused by the granular film structure, thus permitting the actual signal noise to be measured. An alternative approach would be the scanning of a film-based gray scale outside the region of focus, which would also eliminate noise caused by film granularity. All tests were with 7 μm scans. To establish the influence of illumination on the noise behavior, different types of light source were used. The computation was based on an area of 4.4 million pixels per glass plate.

Fig. 5 shows the standard deviation of the color channels for a plate with a density of 0.31 and varying integration time. The noise is most pronounced in the blue channel and increases almost linearly with higher integration time.

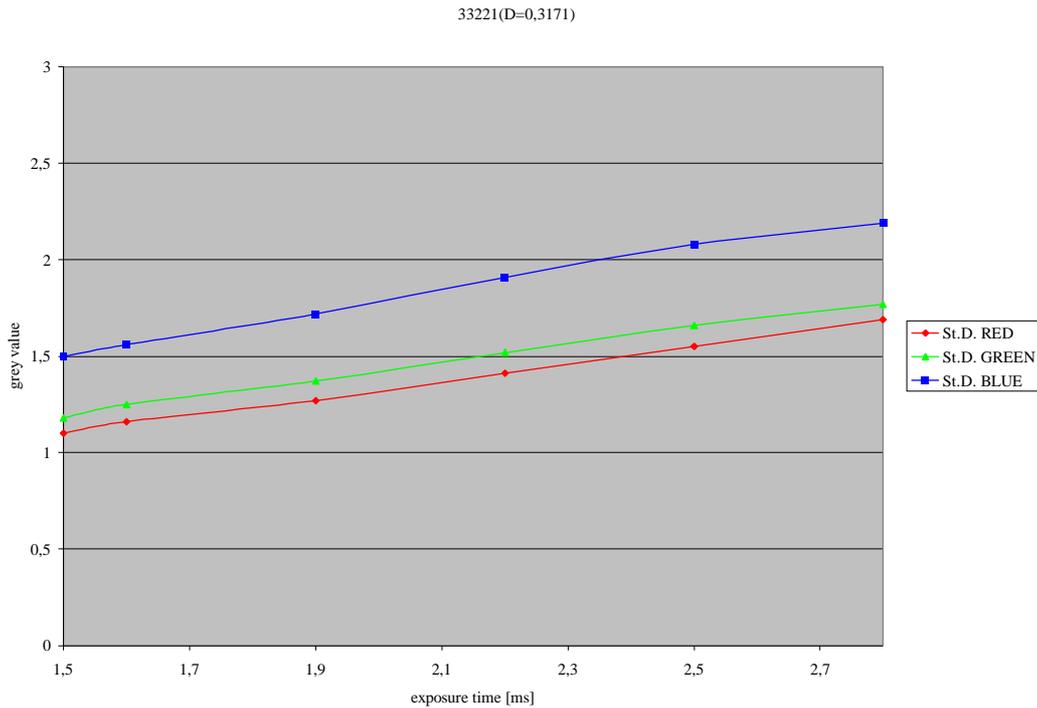


Figure 5. Noise of the sensor as function of integration time, 150 Watt Halogen lamp.

A 250 W halogen lamp was used for the next test. The results show that the noise is reduced as the illumination intensity increases. An explanation for this effect is that the gain values needed for the CCD camera adjustment are lower. The noise can be also reduced by converging the light through a collector lens, which leads also to a lower gain for the analog amplifiers on the CCD camera board.

A difference is noticeable between the individual color channels in Figures 5 and 6, with the noise being most pronounced in the blue channel and virtually identical in the green and red channels. This effect is also attributable to the spectral characteristics of the CCD elements – the blue channel displays the lowest sensitivity – and to the spectral properties of the light source. To decrease this effect, Kodak has developed CCD sensors with an enhanced responsivity called enhanced CFA (Eastman Kodak, 1998).

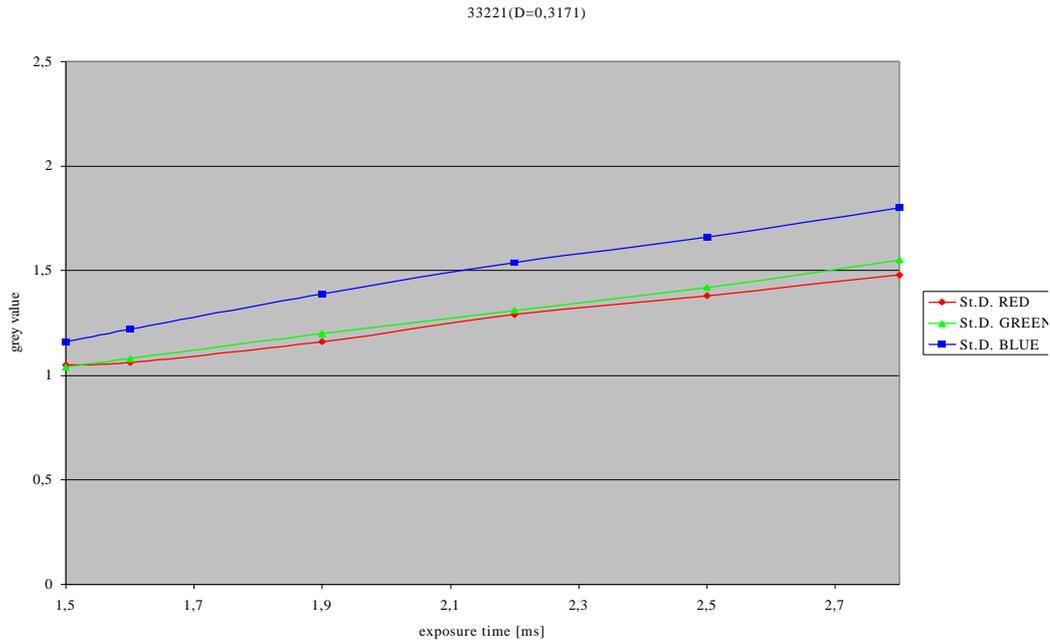


Figure 6. Noise of the sensor as function of integration time, 250 Watt Halogen lamp.

4 INFLUENCE OF AERIAL FILM TYPE AND FILM PROCESSING

Color negative film with an orange (compared to the color negative films with a clear base) has to be scanned with different parameters for each of the three color channels to ensure true-to-color rendition of the image. Fig. 7 shows the gray values vs. density for the three color channels of an AGFA H100 color negative film. It is evident that the curve of the red channel differs considerably from those of the green and blue channels. The reason is the orange film base. The scan was performed with the same integration time and a 1:1 lookup table for all three channels. The above mentioned Kodak step wedge was again used as a test pattern.

AGFA H100 37,8 °C 3 min 18 sec

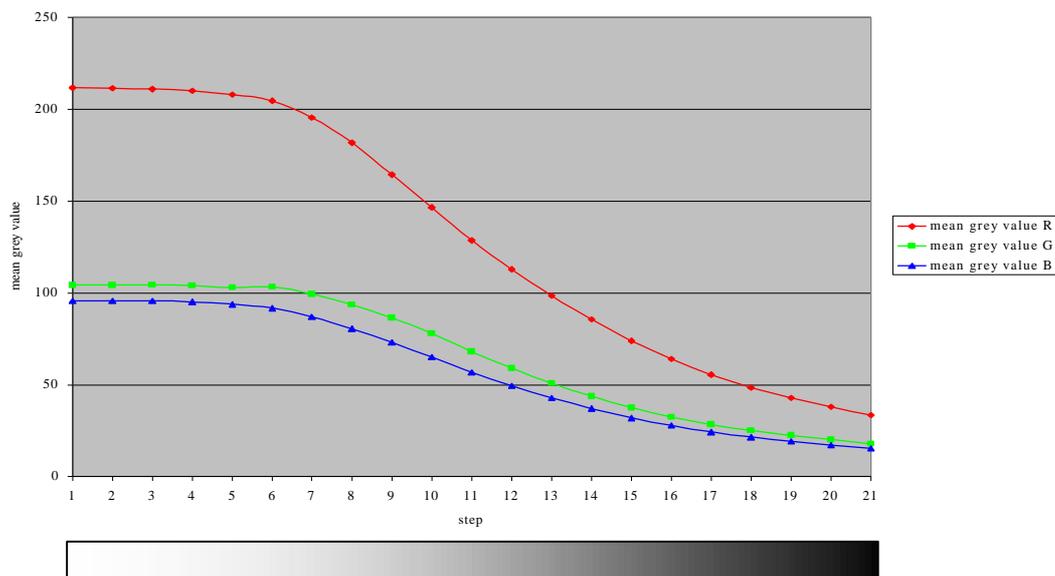


Figure 7. Gray value vs. density for AGFA H100 color negative film. Film processing with temperature and time mentioned at figure top (compare to Fig. 8).

During the test, the same film with the same step wedge, but processed with different temperature and different time, was scanned. The influence of film processing on the variation of the characteristics of the curves is clearly visible in Fig. 8.

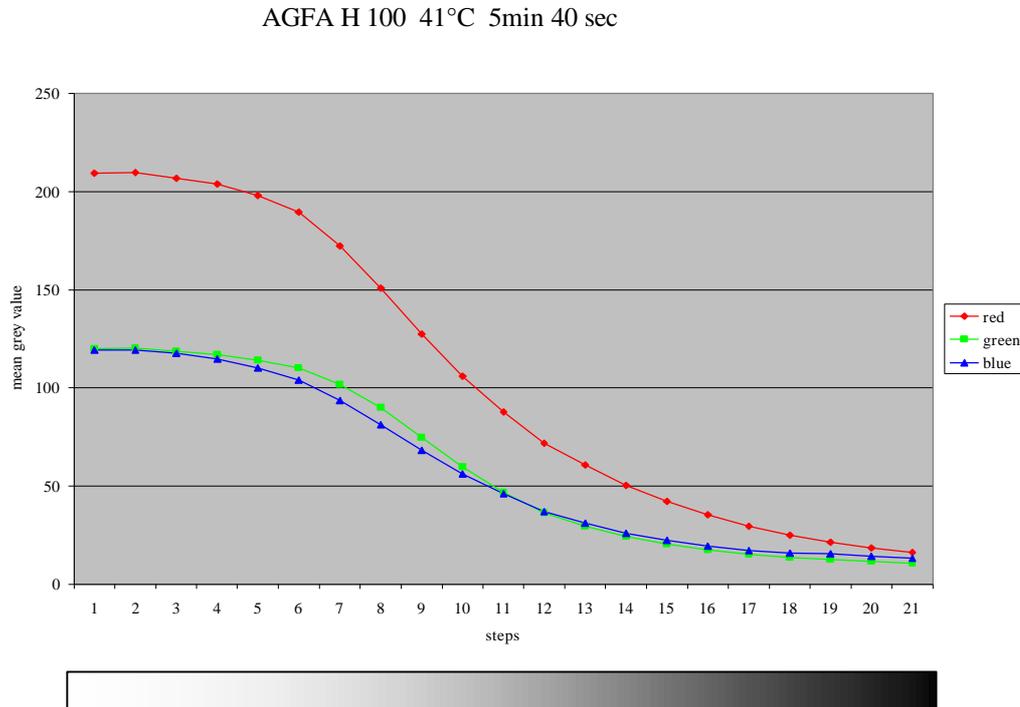


Figure 8. Gray value vs. density for AGFA H100 color negative film. Film processing with temperature and time mentioned at figure top.

The color balance is usually obtained by the use of individual lookup tables for each color channel. The closer the three color density curves of the film are, the less necessity exists to correct color rendition by lookup table manipulation. In the case of strong histogram stretching to achieve color balance, the signal noise of the CCD line will be amplified.

5 CONCLUSIONS

The major conclusions that can be drawn from the above investigations are:

- An improved radiometric quality during the scanning process can be achieved by reducing gray level noise, e.g. by the use of more powerful light sources featuring in particular a large blue component.
- When adjusting the CCD spectral response, care must be taken to ensure maximum coincidence of the characteristics of the individual color channels.
- The fine graduation of the integration time permits optimum setting during the scan to obtain the best possible analog signal.
- A close contact between the film lab and the digital production site helps ensure that film processing can be adapted to the scanning process. Since photography and film processing involve a large number of variables, the best possible process can usually only be found by experimentation. It is always useful if a calibrated gray scale is provided on the film material so that a reference of the film characteristics is available during scanning to support the setting and use of an appropriately tuned lookup table.
- Over- and underexposure should be avoided, if possible, in order to remain within the linear part of the film characteristic.

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