

# CALIBRATION OF THE PHOTOGRAMMETRIC IMAGE SCANNER RASTERMASTER RM1

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## ABSTRACT:

The geometric accuracy and geometric dependencies of the Wehrl Rastermaster RM1 have been tested several times, also because of the change of some hardware components. The accuracy is on the level of usual analytical plotters,

In addition the radiometric reaction was investigated. This was required after the change of the light source which has improved the scanning of the blue spectral range. The inspection of the radiometric behavior by a spectrometer has shown a very good separation of the 3 spectral bands for color images. Within the used area of the TDI-sensor the radiometric homogeneity is sufficient also for areas with very poor contrast. Only in the scan direction some oscillating changes in the range of 1 up to 2 gray values have been identified, which can be seen in very homogeneous areas with very low contrast after contrast enhancement.

The experience with the production rate over 3 years yielded into a procedure which has to be followed carefully. It has been shown that every image has to be inspected visually to be free of the influence of dust and particles which can be located on the film. The radiometric situation has to be checked, especially the fiducial marks are very often different from the other film area.

## 1. INTRODUCTION

The Wehrl Rastermaster RM1 of the Institute for Photogrammetry of the University of Hannover is in production since January 1995 approximately 6 hours per day. Beside the production rate the instrument was analyzed intensively. Against the original equipment, the light source and the drive in the scan direction has been changed. The new light source, which is now standard for the new RM1 has a better characteristic in the blue spectral range. The old friction drive for the y-component has shown some abrasion after 2 years, so it was replaced by a linear motor SP8 S/N 2926 from Nanomotion Ltd which moves on a ceramic plate up to now without abrasion.

Instead of an empiric test of the radiometric behavior, the light source and the filters have been inspected in detail with a spectrometer Zeiss MCC. Together with the known sensitivity over the used spectral range of the TDI sensor, this gives a better information of the radiometric characteristic.

## 2. THE RASTERMASTER RM1

The geometric function of the RM1 is corresponding to an analytical plotter. The movement in the x- and y-direction is controlled by servos based on linear encoders. As sensor a DALSA TDI CL-E1-2048A with 2048 x 96 elements is used. The Time Delay and Integration sensor has the advantage of the use of 96 sensor elements during the scan process for the same image pixel. This extends the sensitivity and causes more homogeneous gray values.

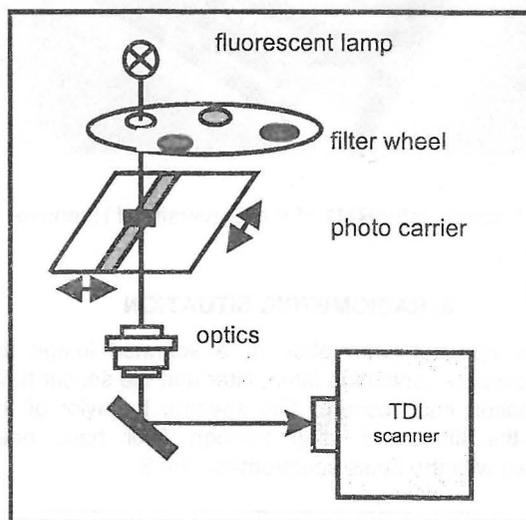


Fig. 1: configuration of the Rastermaster RM1

The pixel size of 12 $\mu$ m corresponds to the usual image resolution of 40lp/mm. Only 1024 pixel of the sensor center are used. This avoids the small loss of light at the more outmost areas of the sensors. So no improvement of the gray values are required, which could enlarge the noise.

A color scan has to be made separate for each color. This takes more time but it guarantees a better color separation than a 3-line-sensor and the blue spectral range with the lower sensor sensitivity can be scanned with a lower speed, creating less noise than just with a numerical change of the gray values.

After 2 years of production with the RM1 some abrasion has been shown at the friction drive. By this reason the most used friction drive in the scan direction has been replaced by a linear motor SP8 S/N 2926 from

Nanomotion Ltd, which moves on a ceramic plate. This has not shown any abrasion up to now.

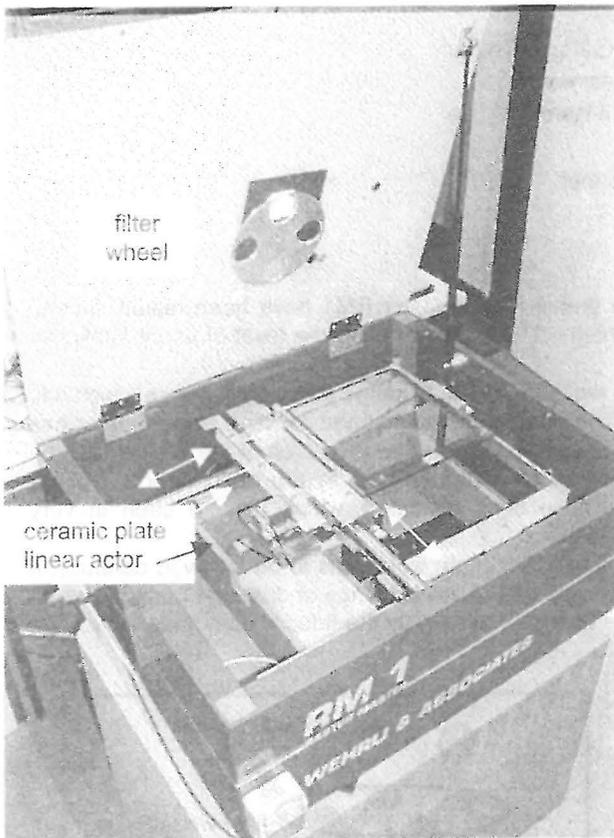


Fig. 2: Rastermaster RM1 of the University of Hannover

### 3. RADIOMETRIC SITUATION

For the spectral information of a scanned image the whole system, containing lamp, filter and the sensor have to be taken into account. The spectral behavior of the lamp, the filter and lamp through filter have been analyzed with the Zeiss spectrometer MCS.

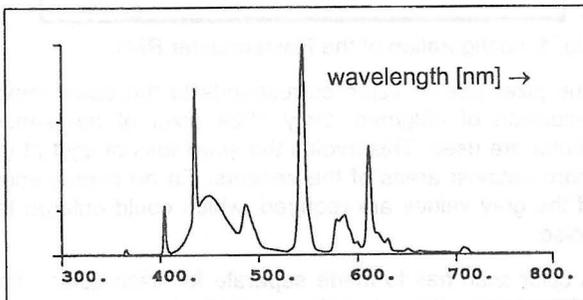


Fig. 3: spectral intensity of the light source

The fluorescent lamp doesn't have a continuous spectrum like an incandescent lamp. In figure 3 the strong intensity in small spectral bands in blue, green and red are shown. This makes it more easy to separate the color in the case of a color scan through filters.

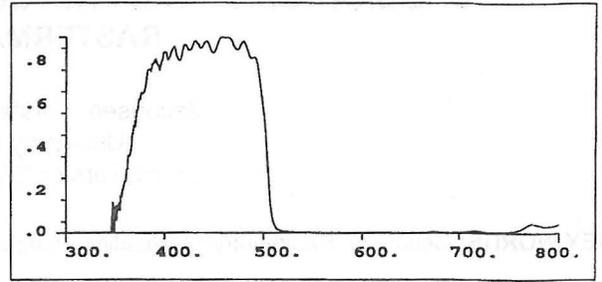


Fig. 4: spectral characteristics of the blue filter

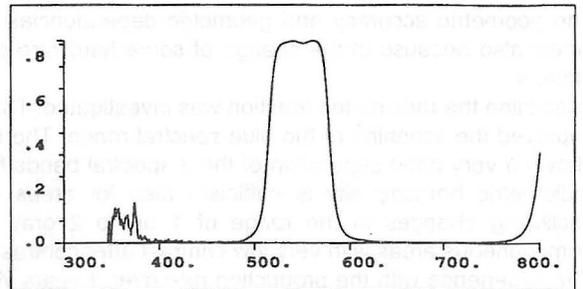


Fig. 5: spectral characteristics of the green filter

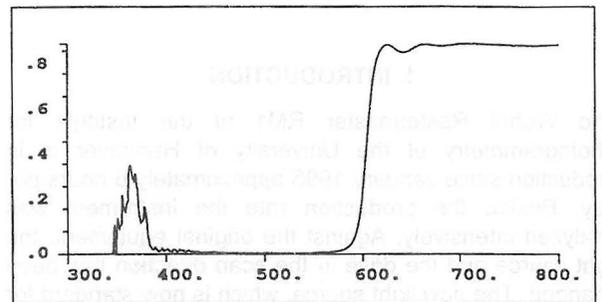


Fig. 6: spectral characteristics of the red filter

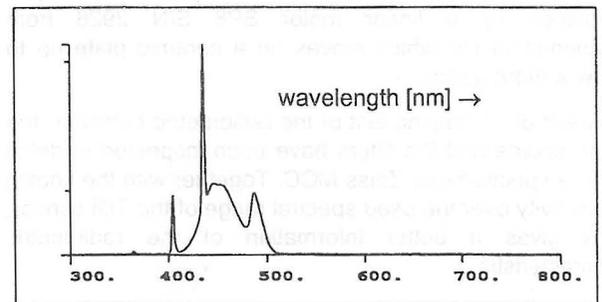


Fig. 7: spectral intensity - light source through blue filter

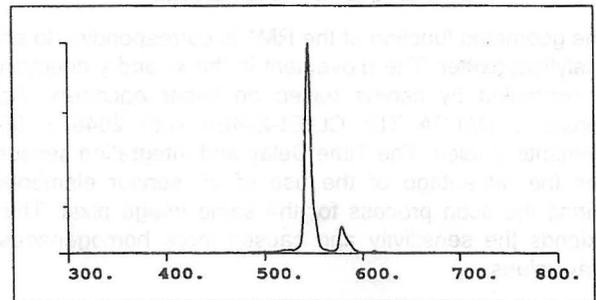


Fig. 8: spectral intensity - light source through green filter

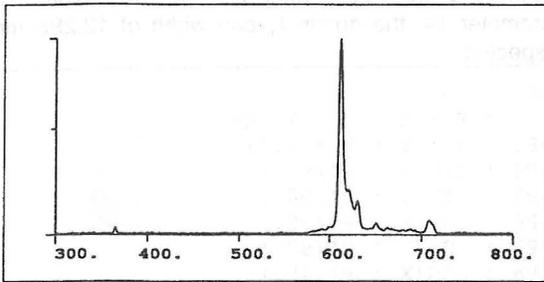


Fig. 9: spectral intensity - light source through red filter

In figure 4 up to 6 the spectral characteristics of the used filters are shown. The spectral separation of the filters are slightly overlapping. This usual situation has no influence like the transmission in the ultra violet range (<400nm) and the transmission in the infra red range above a wavelength of 750nm, which is cut of in the graphics. The energy of the light source is limited to the spectral range from 400nm to 720nm, so the transmission of the filters outside this range is unimportant and it has a reduced intensity in the overlapping areas of the filters.

Important is the intensity of the light source through the filters (figure 7 – 9). This shows a very clear separation of the filters the 3 basic colors. The unequal distribution of the energy in the 3 spectral ranges is not causing problems because the color of the scanned images is always a mixture of the 3 color layers of the film and it is not a continuous spectrum.

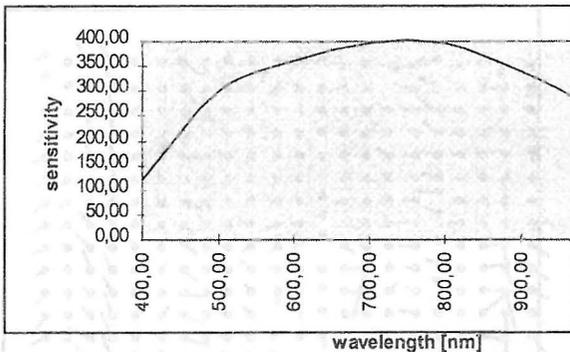


Fig. 10: spectral sensitivity of the DALSA CL-E1

In addition to the intensity of the light through the filters, the sensitivity of the used sensor is important. In general the CCD-line or -array sensors are showing a similar dependency as a function of the wavelength like the used TDI-sensor DALSA CL-E1 (figure 10). In the blue spectral range they are not so sensitive like in green or in red. The integrated intensity of the light through the filters showed the blue range with 44% and green with 94% of the power in the red range. The power is added in the case of a scan without filters. The Rastermaster RM1 has to scan color images separate for each spectral range. This is more time intensive, but it includes the advantage of a scan with the optimal speed. The blue scan will be done with a slower speed and has by this method a lower noise than in the case of a scan with a 3-color CCD-line-sensor. The 3-color-CCD-line sensor has to equalize the gray values by a lookup table and this enlarges the noise linear in the blue spectral range by the factor 2.

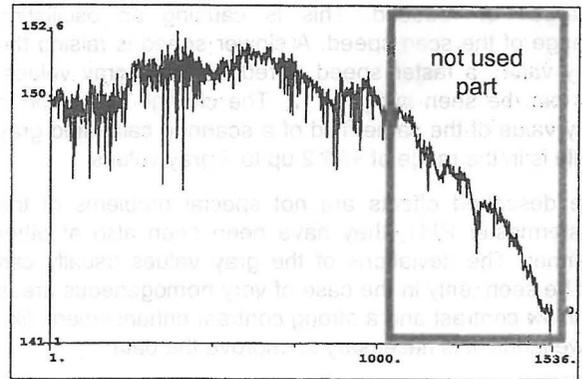


Fig. 11: gray values over the sensor line

Not only the spectral dependency is important, the sensitivity of each sensor element should be checked. The used TDI-sensor always takes for each pixel the mean response of 96 sensor elements, so the situation is much better than with simple CCD-line-sensors. But nevertheless also the TDI-sensors are showing differences in the sensitivity of the mean values over 96 physical elements. A calibrated gray scale has been scanned. Figure 11 shows the mean values of the columns over 600 lines. Of course this may be influenced by dust and unavoidable dirt, but it is realistic for usual operation. Not the whole sensor line has been inspected, the first 512 elements are not recorded, but the standard program of the RM1 is only using the 1024 center elements. The effect of the loss of light for the not used part can be seen on the right hand side of figure 11.

Figure 11 doesn't show just a straight line, some pixel are less sensitive. The difference in the sensitivity are dependent upon the gray values itself. For the mean gray value 248, the gray values do have a mean square difference against the mean value of +/-1.5 gray values. The mean square differences are approximately linear depending upon the gray value, so for the gray value 15, the mean square differences are reduced to +/-0.1. The gray values can be improved to a more equal situation by an individual correction with a constant shift plus a factor linear depending upon the gray value. Based on the used 17 different gray scales, such an improvement leads to remaining +/-0.43 gray values for the gray values 250.

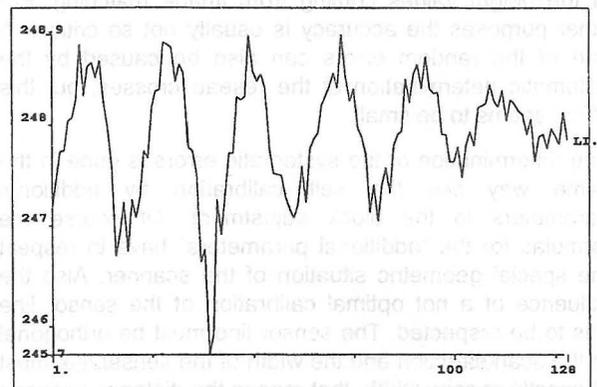


Fig. 12: mean gray values in scan direction - influence of changing scan speed

Like an analytical plotter, the movement of the sensor line is controlled by a servo. If the actual position does not agree with the planned position, the speed will be enlarged or reduced. This is causing an oscillating change of the scan speed. A slower speed is raising the gray value, a faster speed is reducing the gray values, this can be seen in figure 12. The change of the mean gray value of the same field of a scanned calibrated gray scale is in the range of +/-1.2 up to 2 gray values.

The described effects are not special problems of the Rastermaster RM1, they have been seen also at other scanner. The deviations of the gray values usually can not be seen, only in the case of very homogeneous areas with low contrast and a strong contrast enhancement, like in wetlands, it is necessary to improve the data.

#### 4. GEOMETRIC CONDITION

The radiometric problems have been described at first, because there are the main problems. But also the geometric accuracy should be checked because with some other scanner types problems have been seen. The Rastermaster RM1 has been checked several times because we have made some hardware modifications and we have analyzed also a different sensor with the same scanner. The geometric calibration was made with a reseau platen with 121 x 121 grid crosses. In any case the scan was made with 12µm pixel size. The positions of the grid crosses are known with an accuracy better than 1µm. The center position of the scanned reseau crosses have been determined by an optimized program. Not all reseau crosses can be determined, but the final 12 803 are still enough for a detailed analysis.

With the Hannover program POCOR the calibrated reseau positions are transformed affine to the determined positions and analyzed for random and systematic effects. Affine errors of the scanner are not taken into account because usual aerial images do have affine errors and must be transformed affine to the calibrated fiducial marks. Such a transformation also will also respect affine errors of the scanner.

The separation of random and systematic errors is required for a better understanding. Systematic errors can be respected automatically by a block adjustment with self calibration by additional parameters, but it is also possible to use the determined effect for an improvement of the height values coming from image matching. For other purposes the accuracy is usually not so critical. A part of the random errors can also be caused by the automatic determination of the reseau crosses, but this effect seems to be small.

The determination of the systematic errors is done in the same way like the self calibration by additional parameters in the block adjustment. Of course the formulas for the "additional parameters" have to respect the special geometric situation of the scanner. Also the influence of a not optimal calibration of the sensor line has to be respected. The sensor line must be orthogonal to the scan direction and the width of the sensor line must fit exactly to scan width, that means the distance between the neighbored scan lines. This special effect is

determined with the parameter 14 (see table 1). In parameter 14, the nominal scan width of 12.288 mm is respected.

-P1
-P2 * X * X * Y * 1.0E-6
-P3 * X * Y * Y * 1.0E-6
-P4 * SIN(X * PI/90.)
-P5 * SIN(Y * PI/90.)
-P6 * COS(X * PI/90.)
-P7 * COS(Y * PI/90.)
-P8 * COS(X * PI/45.)
-P9 * COS(Y * PI/45.)
-P10 * SIN(X * PI/45.)
-P11 * SIN(Y * PI/45.)
-P12 * COS(X * PI/22.5)
-P13 * COS(Y * PI/22.5)
-P14 * (X- INT(X/12.288.)*12.288-6.144)
-P15 * ((Y-120)**3 -3375000.* 1.0E-6

table 1: formulas for the determination of systematic scan errors

The very high number of observations enables a clear separation of the systematic effects. In the latest check of our Rastermaster with one exception all parameters are significant, in the mean the student test values are reaching approximately the value 30. The calibration of the sensor line was done in a sufficient manner, the determined effect at the end of the sensor line was only 1µm. The mean square of the random plus the systematic errors are in the range of +/-4 µm, that means, it can be compared with the accuracy of analytical plotters.

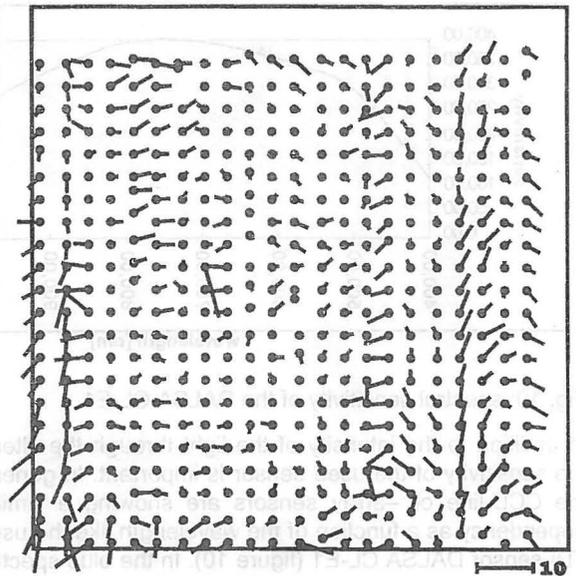


Fig.13: remaining errors after elimination of major systematic errors (reduced number of vectors)

After reduction of the major systematic errors by the "additional parameters" shown in table 1, in both coordinate components only +/-1.9µm are left. But figure 13 also shows some smaller remaining parts with local influence. With just 15 parameters for 12803 observations, only the major trend of systematic errors can be determined. A covariance analysis can give more detailed information about this. With the original discrepancies there are larger covariance's, that means

correlation's, over larger distances (figure 14). This is strongly reduced for the remaining errors (figure 15).

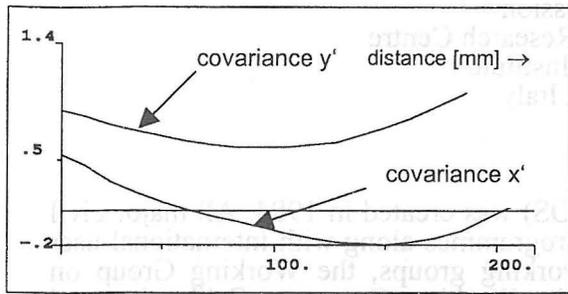


Fig. 14: covariance function of the original discrepancies at the reseau crosses

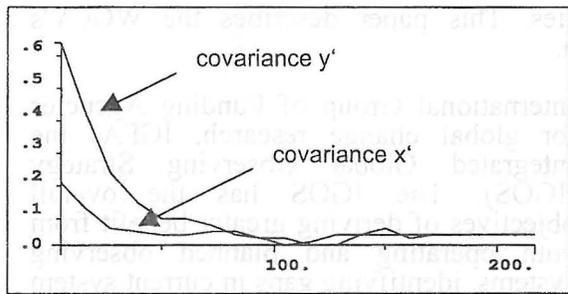


Fig. 15: covariance function of the discrepancies after elimination of the major systematic errors

The covariance values are larger for the  $y'$  –direction (scan-direction) than for  $x'$ . This can be caused by some dynamic effects. A comparison between figure 14 and 15 should take into account also the different reference values ( $rmsx'$ ,  $rmsy'$ ), which are different by the factor 2.

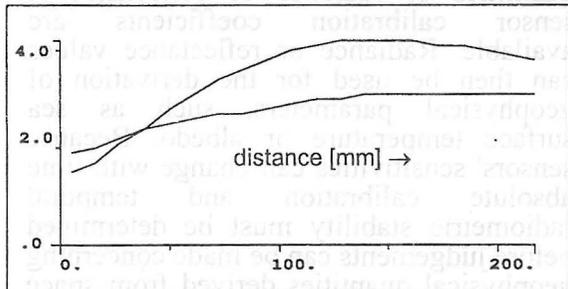


Fig. 16: relative standard deviation, original discrepancies

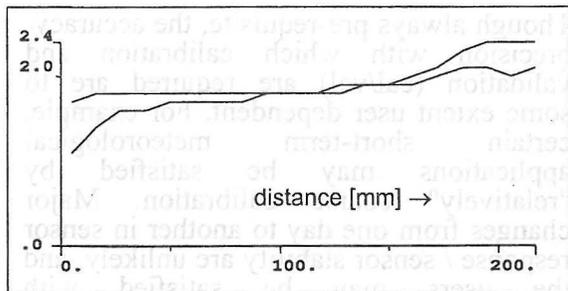


Fig. 17: relative standard deviation after elimination of the major systematic errors

The covariance function only includes the information about the dependency of neighbored discrepancies, for practical applications the relative standard deviation – the accuracy of an observation in relation to another, depending upon the distance - is more important. The relative accuracy of the original discrepancies starts with  $rsx=+/-1.9\mu m$  and  $rsy=+/-1.5\mu m$  for directly neighbored points and goes up to  $rsx=+/-3.1\mu m$  and  $rsy=+/-4.2\mu m$  for larger distances. For short distances it is very close to the remaining accuracy after elimination of the major systematic effects. The relative accuracy of the discrepancies after elimination of the major systematic effects is not so much depending upon the distance, it goes from  $rsx=+/-1.7\mu m$  and  $rsy=+/-1.1\mu m$  for short distances up to  $rsx=+/-2.1\mu m$  and  $rsy=+/-2.4\mu m$ . This confirms the other mentioned results.

## 5. EXPERIENCES

The production over longer time period resulted in a save standard procedure. It has been shown that the inspection of every scanned image for dust and dirt particles and also for the sufficient settings is required. Especially the fiducial marks should be checked because their contrast and photographic density is often different from the image itself. Problems are existing with the scan of black/white negative images. In the case of larger contrast it is better to scan a diapositive copy. But this problem exists also for other scanner.

In a test project images have been scanned with the Rastermaster and also with the SCAL. The final results of image correlation with OrthoMax in relation to independent check points resulted in very similar differences.

## 6. CONCLUSION

The geometric accuracy of the Rastermaster RM1 is sufficient for all purposes. The radiometric resolution is still limited for all types of sensors in relation to the photographic density range of photos, by this reason, the settings of the scanner have to be handled carefully. The special type of light source has an advantage for the color separation. Each band can be scanned in the optimal manner.

## ACKNOWLEDGEMENT

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