GEOMETRIC AND RADIOMETRIC ANALYSIS OF A PHOTOGRAMMETRIC IMAGE SCANNER

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ABSTRACT:

The digital (hardcopy) photogrammetry makes a very fast progress, but for aerial photogrammetry the primary data acquisition will be based in the near future on analog photos. The loss of geometric accuracy and the loss of radiometric information caused by the scanning of photos with the photogrammetric image scanner Rastermaster RM1 of the University of Hannover has been investigated.

The dynamic range of the TDI sensor included in the scanner is limited to 1.5D and the relation between the gray values and the photographic density is not linear. That means there is a loss of information especially in the dark parts of the scanned images. This can be accepted for positive black and white or color film, but it is causing problems with negative films. The scanning of color images with filters will not led to optimal results in the blue spectral range. These problems are not special problems of the Rastermaster, it is a general problem of the CCD-linear arrays and CCD-arrays.

The geometric accuracy of the Rastermaster is corresponding to an analytical plotter, that means it is sufficient for all purposes of digital photogrammetry.

1. INTRODUCTION

The amount of information included in an aerial photo cannot be transferred with the today technique into any type of storage within the time period available from exposure to exposure. By this reason also in the next future photos have to be scanned for getting digital images with sufficient resolution. Line scanners do not have the number of pixels corresponding to a photo (~18400 pixels would be required) and the geometry cannot be compared.

It has been shown that only image scanners designed for photogrammetric purposes do have a sufficient accuracy. Drum scanners with diodes do have a better radiometric characteristics than CCD-lines and arrays but the geometric quality is usually not better than ±50µm, or with some special calibrations of new scanners ±25µm and this only can be accepted for orthophotos. Image correlation, data acquisition for aerial triangulation and photogrammetric stereo measurements have to be based on digital images with position accuracy's not less than ±5µm.

Because of the limited budget of the Institute the photogrammetric image scanner Rastermaster RM1 from Wehrli & Associate Inc. has been chosen. Our version of the RM1 needs including the handling 30 minutes for the scanning of an aerial photo with 12µm pixel size. All the other technical details are corresponding to the other photogrammetric image scanners. In the meantime the scanning speed has been changed by Wehrli Ass.. During the decision phase the amount of images which have to be scanned was underestimated, this seems to be typical. In the period of now 14 month the scanner was intensively used. If a scanner is available, the request for digital images automatically is raised.

2. THE RASTERMASTER RM1

The RM1 of the Institute is in use since January 1995. Meanwhile it is changed by the company The light source is now different, so the images can be scanned with higher speed and a color sensor is available. The geometric behavior is the same, only some parts are reconstructed for improving the life time and reducing the required service.

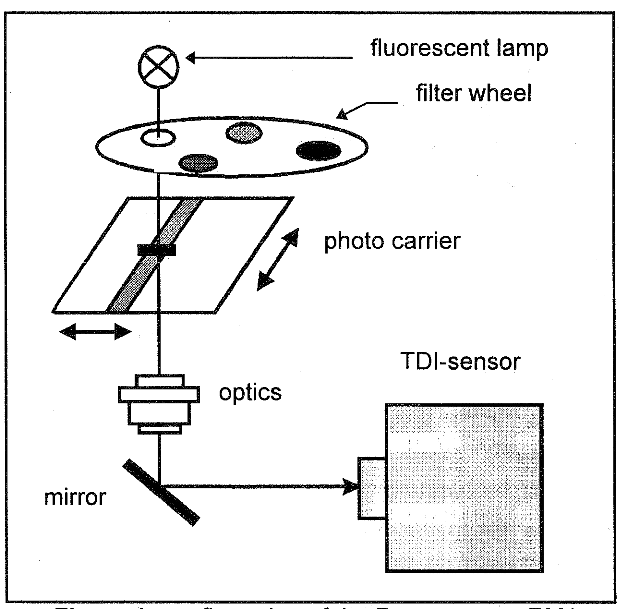


Figure 1: configuration of the Rastermaster RM1

The general geometric design is corresponding to an analytical plotter. The movement of the photo carrier is controlled by servos based on linear encoders. The plate is moved by a friction drive. With a working space of 245mm•245mm no problems for handling standard size aerial images are existing.

The used time delay and integration sensor (TDI) DALSA CL-E1-2048A has a length of 2048 elements and integrates over 96 pixels, that means, it is not a line, it is an array with 2048•96 elements. The integration of the TDI-sensor over 96 elements reduces the noise and systematic line errors by the factor of 96 and raises the sensitivity 80 times against an individual CCD-element. This sensor is also used in another photogrammetric image scanner.

The RM1 is using only 1024 of the 2048 rows. The active part can be selected by the scanner control data, usually the center part is used. The sensor has no possibility for a selection of the spectral range, this only can be done by a computer controlled filter wheel with the standard red/green/blue selection. The transmitted light from the fluorescent lamp is passing through an APO-RADOGON-D lens system from Rodenstock over a mirror to the sensor. By the projection the original pixel size of 13µm in the sensor is changed to 12µm in the scanned image.

3. GEOMETRIC ACCURACY

If the digital images shall not be used just for orthophoto production, the loss of accuracy caused by the scanning is important. The geometric quality of the scanner should correspond to analytical plotters, it has the same meaning to the data acquisition. The geometric accuracy should not be mixed with the pixel size because a subpixel standard deviation can be reached. If the image target has a size of one pixel, by theory the location is defined with ±0.3 pixel, but usually the elements are defined by a higher number of pixels. Well defined, targeted points can be measured with up to ±0.02 pixels (Bösemann, Jacobsen 1995).

The basic construction of the RM1 is corresponding to an analytical plotter, but there are few additional error sources because opposite to the analytical plotter the image coordinates are not just determined for a point, a line of pixels is scanned at the same time. The lack of flatness of the photo on the photo carrier has only an influence corresponding to the view direction of the sensor line. the center part of the sensor is used, in maximum the inclination of the imaging ray is corresponding to 6.144mm / 150mm = 1:24. That means, a lack of flatness of the photo of 0.1mm is causing a 4 µm dislocation in maximum, in the linear mean 2µm.

The geometric effect of the sensor line itself is negligible, it is far below 1µm. The measuring system is based on servos together with a glass scale from RSF Elektronik. A resolution of 0.5µm is reached and the used type MSA6707 shall have an accuracy of +/-3µm. The x- and the y-axis should be orthogonal, this has to be calibrated. Finally we do have the same problem like in analytical plotters. Usually an error in affinity and angular affinity is unimportant because it is eliminated by the inner orientation which has the be done at least by affinity transformation in relation to the fiducial marks because of affine errors of the original photos.

The location of the sensor line in the image has to be calibrated. The swath width shall correspond to the distance between the neighbored scan lines and the sensor line shall be orthogonal to the scan direction (see figure 2).

The RM1 has been checked by means of 2 different reseau platen, one from the Rollei Reseau Scanner with 121•121 reseau crosses with a spacing of 2mm and one with 11•11 lines with a grid spacing of 12.5mm. For both platen the calibrated grid coordinates are available with an accuracy < ± 1µm. The platen have been rotated slightly against the instrument axis to avoid the check of only few rows and columns. At first the reseau cross positions in the scanned images have been measured manually with a pointing error of ±2µm, later on this has been done by correlation with an accuracy <±1µm.
The discrepancy between the measured and transformed grid coordinates to the calibrated values have been analyzed for random and systematic errors. The separation of the systematic errors can be made in the same way like the self calibration in bundle block adjustment. Additional unknowns which are able to compensate the typical geometric problems have to be introduced.

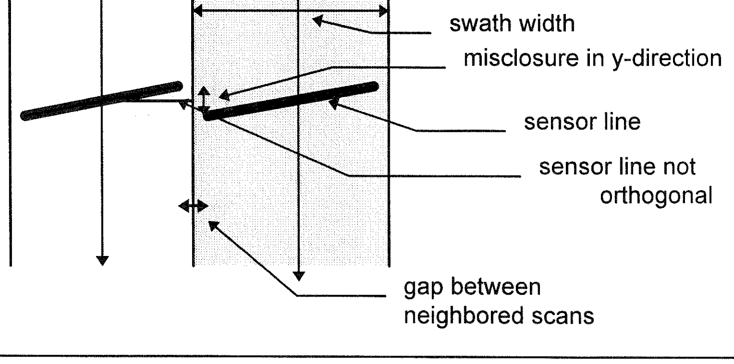


Figure 2: location of CCD-lines of neighbored scans, errors of mechanical sensor calibration

$x' = x - P1\,x'$
$x' = x - P2 \bullet X \bullet Y \bullet 1.0E{-6}$
$x' = x - P3 \bullet X \bullet Y \bullet Y \bullet 1.0E{-6}$
$x' = x - P4 \bullet SIN(X \bullet \pi/90.)$
$x' = x - P5 \bullet SIN(Y \bullet \pi/90.)$
$x' = x - P6 \bullet COS(X \bullet \pi/90.)$
$x' = x - P7 \bullet SIN(Y \bullet \pi/90.)$
$x' = x - P8 \bullet COS(X \bullet \pi/45.)$
$x' = x - P9 \bullet SIN(Y \bullet \pi/45.)$
$x' = x - P10 \bullet SIN(X \bullet \pi/45.)$
$x' = x - P11 \bullet SIN(Y \bullet \pi/45.)$
$x' = x - P12 \bullet COS(X \bullet \pi/22.5)$
$x' = x - P13 \bullet COS(Y \bullet \pi/22.5)$
$x' = x - P14 \bullet (X - INT(X/12.288) - 6.144)$

Table 1: set of formulas for the separation of systematic errors

The set of formulas shown in table 1 has been used for the separation of systematic errors. A corresponding set of formulas has been used also for y-component. This strategy is corresponding to the determination of systematic image errors in the block adjustment with selfcalibration by additional parameters. The same statistical tests like used in program BLUH have been made (Jacobsen 1982 and 1984).

The scanner was tested several times over a longer time period. Up to the replacement of one friction drive the systematic errors have not changed. But the change of the friction drive by the Institute has had a strong influence to the geometry as visible in the comparison of figure 3 and 4. Before the replacement the original discrepancies at the transformed reseau points have been ±4.7µm (±4.2µm without the influence of the manual measurement). This value can be splitted into a random part of ±2.9µm and a systematic part of ±3.0µm. After the change, the total effect has reached ±6.8µm based on an automatically point determination of 11 507 points, which can be explained as ±6.3µm systematic part and 2.7µm random part. (see figure 4). The large size of the systematic errors have been caused by lubricant on the reference rod for the x-direction. After cleaning the rod, the total mean square error was drastically reduced to ±3.3µm at 11708 reseau crosses. This small size again can be splitted into **±2.6µm systematic error** (figure 6) and **±2.0µm random error** (figure 5). Of course the systematic error can be used for an improvement of determined image coordinates, but in the case of such a small size, corresponding to the accuracy of analytical plotters, the meaning is not so important.

Together with the determination of the systematic errors, the rotation of the sensor line against the scan direction and the fitting of the swath width to the spacing between neighbored scans can be computed by the parameter 14. It was possible to reduce the remaining error to approximately ±1µm.

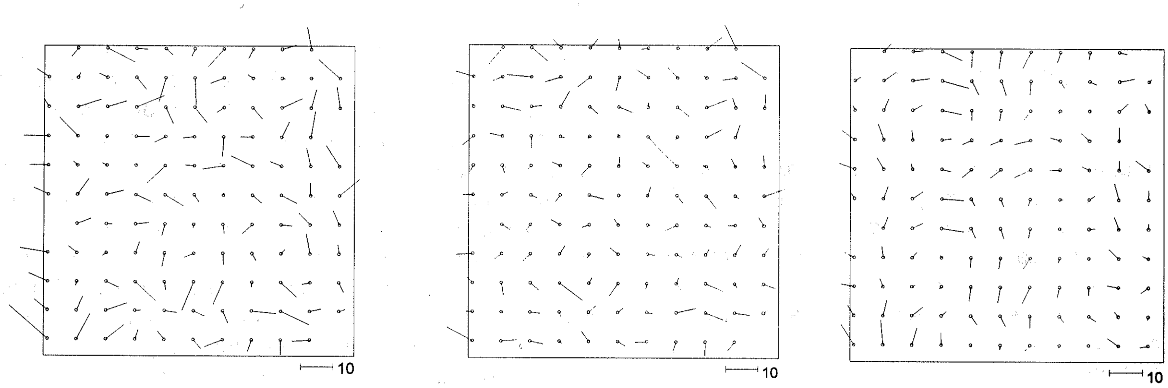
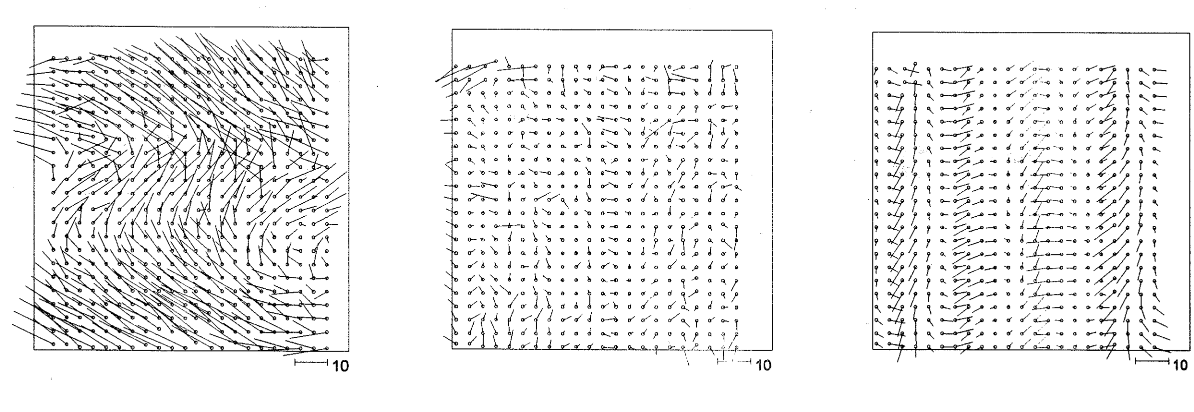


Figure 3: ↑ results of the RM1 calibration ↑ [vector scale 10µm]
original discrepancies — random part — systematic part

↓ results of the RM1 calibration after replacing the friction drive ↓
Figure 4: discrepancies influenced by lubricant on rod — **Figure 5:** random part after cleaning — **Figure 6:** final systematic errors



4. RADIOMETRIC CHARACTERISTICS

In general the fast CCD-linear arrays and CCD-arrays do have a limited dynamic range in relation to the photos. The Rastermaster is using a depth of 8 bit corresponding to 256 gray values. This is usually sufficient. The relation between the gray values and the optical density of the film has been determined by means of a calibrated Kodak gray scale. The whole range of the scanner settings, that means speed and diaphragm, has been checked. Figure 7 gives an overview over some of the results. Caused by the different settings the relation between the gray values and the optical density is primarily shifted in the direction of the optical density. The dynamic range of approximately 1.5D is not changed by this.

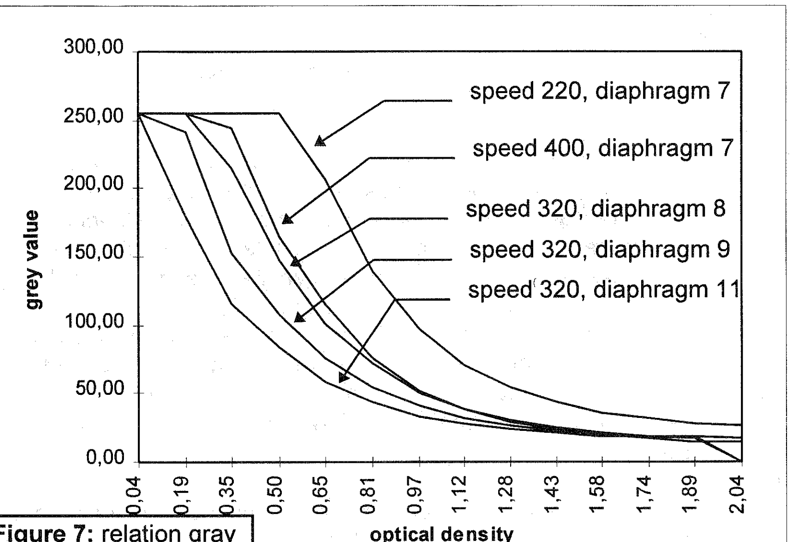


Figure 7: relation gray value - optical density

The relation between the gray values and the optical density is far away from a linear function. Of course it is possible to linearize it with a look up table but this has only an advantage for the visual interpretation and the disadvantage of a loss of information in the bright part. If the digital image shall be used for an image correlation, better results can be reached with the original gray values. The separation of elements with different optical density in the dark image areas (larger optical density) is limited, that means it is difficult to scan photo negatives. In the case of photo positives the important information is included in the bright parts, here we do have a very good separation but information in the shadows are reduced. It is also not a problem to scan positive color film in the panchromatic mode. Here we do have the same relation like with photo positives.

If a color image shall be scanned in color, this has to be done three times with the computer controlled filter wheel. It is enlarging the scanning time at least by the factor of 3. Especially with the blue spectral range there are some problems. The sensitivity of the used sensor is much less in the blue range (~400 - 490nm) and with the light source of the RM1 installed in the University of Hannover no satisfying results have been achieved. In the meantime another light source is available with a 5 times enlarged brightness.

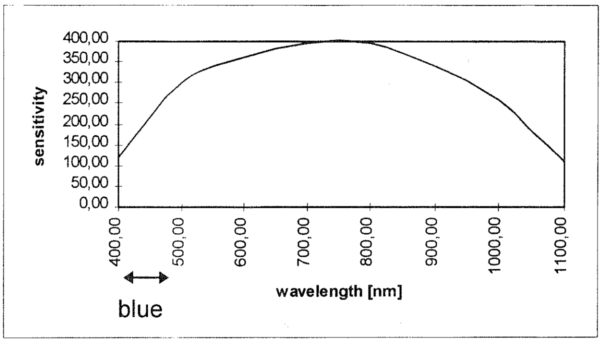


Figure 8: spectral sensitivity of the sensor

Of course in a usual aerial positive color film the blue component is not very intensive, but this also should not be lost. More important is the blue color in the case of false color images. With the new color line sensors and an improved illumination the problem is reduced, but it is still existing.

Due to the fact of a limited density range, the optimal selection of the scanner settings is important. An over-saturation of the CCD-elements has to be avoided because it can cause a very strong blooming effect. In the extreme case the whole sensor line can get blind, that means a larger area will have the gray value 255. By this reason we cover the area around the scanned photo with cardboard. The optimal results are achieved if the bright parts of the photos are just getting the gray values 255, that means there is a loss of information in the dark parts of the images. Usually this is not causing problems in the case of positive black and white or color film.

The empirical determination of the optimal scanner settings is very time consuming. It takes approximately 30 minutes with the RM1 and it has to be done at least for every photo flight. Within a photo flight the settings only have to be changed if a general change of the landscape is within the area. As mentioned before, the optimal settings are shifting the bright parts of the photos just to the gray value 255 to avoid an over-saturation. It is much more fast to scan the photo transparencies with a desktop scanner like the HP Scanjet IICX. In the Institute of Photogrammetry and Engineering surveys we only do have the possibility to use the desktop scanner with reflected light, that means the scanned transparencies are not looking very nice. The density range of the HP Scanjet is also smaller in relation to the RM1 (see figure 9) and the gray values cannot be compared directly, but the density of the bright parts can be measured and with an empirically developed table the optimal RM1-settings are available within one minute.

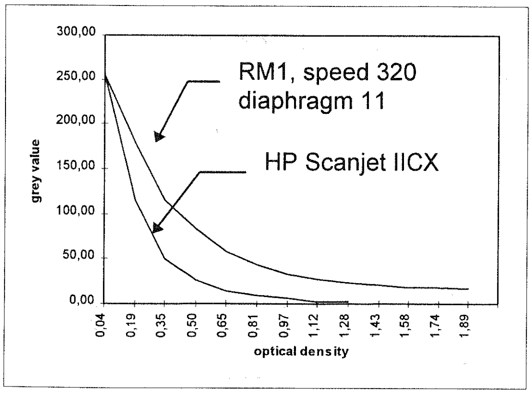


Figure 9: relation gray value - optical density for the HP Scanjet IICX compared with the RM1

The general limitation of CCD-lines and arrays with the color and the density range are only allowing a limited quality of generated orthophotos. By this reason in some sensitive projects, the photos have been scanned twice - at first with the RM1 for the image correlation and then with a drum scanner for getting the optimal color information.

5. RESOLUTION, MTF

The Rastermaster has a pixel size of 12µm•12µm. If this shall be compared with the photographic resolution, by theory it has to be multiplied with the Kell-factor (2•√2 = 2.8) for getting the minimal size of a linepair which can be identified as a linepair and not as homogeneous gray. In practice the relation between the size of a linepair and the pixel is more close to 2.0. With this relation the size of the linepair is 24µm corresponding to 42 lp/mm. It is not a matter of course that this will be reached in practice by the scanner. Some desktop publishing scanners are existing, where this relation is totally missed. For checking a test pattern (Siemens star) was scanned.

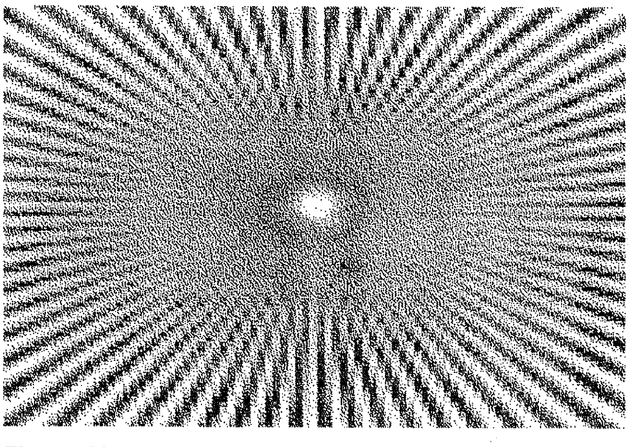


Figure 10: scanned test pattern

Based on the test pattern a resolution of 40 - 42 lp/mm is available with the Rastermaster. This corresponds to the pixel size of 12µm, but also to the usual resolution of aerial photos. That means, a higher resolution is not required. The resolution includes only the information about the radiometric quality for a high image frequency. The loss of contrast for lower image frequency can be described with the modulation transfer function (MTF).

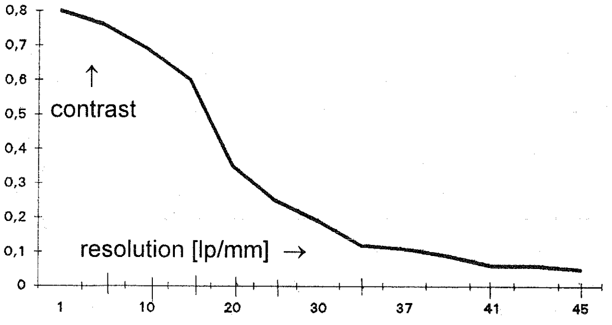


Figure 11: modulation transfer function of the RM1

6. Operational Problems

The RM1 is controlled by a PC Pentium 90. This PC is only used for the scanning, further processing of the digital images usually happens on workstations, that means the data have to be transferred. The data transfer takes not much less time than the scanning and during this time the scanner is blocked. By this reason the PC was equipped in total with 8Gb disc space to store all images of a day. The data transfer then can be made by batch process over night. In addition a CD-writer is connected to the PC to allow also the output on CD.

The scanning of one image including the handling takes approximately 30 minutes, this is sufficient under the conditions of a University, but we hope to reduce it with a new light source.

Once in a group of digital images a shift of a scan-line by 1 up to 2 pixel could be detected. This may be caused by abrading material from the friction drive of the photo carrier. After cleaning the wheel, the problem has not been seen again. A loss of reference has been seen also in digital images scanned with other scanner types and also in analytical plotters. By this reason the scanned images should be checked not only for the correct radiometric representation, but also for a loss of reference. The abrading of the friction drive made it necessary to replace the friction drive after one year of operation. The material has now been changed from aluminum to stainless steel, so the problem may be solved.

As mentioned before it is necessary to cover the area around the photos on the photo carrier by cardboard to avoid an over-saturation of the sensor. Especially the area around the fiducial marks may cause problems if the settings are not optimized.

An investigation of the warm-up of the lamp and the sensor has shown a strong influence during the first 3 minutes. The gray values of an area of the gray scale has changed from the switch on to 3 minutes later from 147 to 179. After 3 minutes stable conditions have been reached with no stronger change than 2 to 3 gray values. The remaining changes may be caused by a change of the voltage.

7. Conclusion

The CCD-lines and arrays do have a limited dynamic range in relation to aerial images, by this reason it is necessary to use the optimal settings for the scanner. The time consuming empirical determination can be replaced by a pre-scan with a desktop scanner. Based on the pre-scan with a developed table the settings can be found within one minute. Nevertheless a loss of information will happen in the dark parts. By this reason problems are existing in scanning photo negatives. With photo positives and color images which shall be scanned only black and white, no real radiometric problems are existing.

The geometric accuracy of the RM1 corresponds to an analytical plotter, that means, it is sufficient also for jobs where precision is required like image correlation and block triangulation.

The pixel size of 12µm is corresponding to the usual resolution of aerial photos. A smaller pixel size will not improve the quality of the digital image. Because of the large file size of the digitized images (~360 Mb for one channel, 1.06 Gb for the 3 color channels together) very often the pixel size is reduced to 24µm.

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Figure 12: Rastermaster RM1