# ACCURACY AND APPLICATION POTENTIAL OF THE 94 MEGAPIXEL RGB MACRO-SCANNING CAMERA PENTACON SCAN 5000

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**ABSTRACT**

A macro scanning camera system generates a large image format using a moving linear or array sensor scanning the image plane. Such scanning systems offer a very high resolution connected with moderate costs in comparison to full format high resolution digital cameras. An obvious deficit of the camera concept is the fact that image acquisition takes some time, limiting the concept to static applications. In addition, the accuracy potential is limited by mechanical parts involved in the image formation process.

In the paper the scanning system Scan 5000 (Figure 1), made by Pentacon (Germany), will be presented and its accuracy will be investigated in detail. The system comprises a linear RGB CCD-sensor with 8192 pixel per colour, moving through the image plane in 12000 steps. In this way it simulates a 94 megapixel 24-bit RGB array sensor and represents a very suitable tool for applications in the field of architectural photogrammetry and cultural heritage documentation. The camera offers the potential to substitute analogue large format cameras, which are still frequently used in this field.

The paper will concentrate on the question whether the high resolution of the camera is accompanied by an appropriately high accuracy. For this purpose multiple images sets of a 3D test field were captured and processed in a bundle block adjustment. The results will be presented and analysed. In addition, the test field was captured with the digital 14 megapixel array sensor camera Kodak DCS Pro 14n in order to compare the geometric accuracy potential of the line scanning camera with that of a full frame digital camera. It was found out that – despite the different sensor size of 14 vs. 94 megapixel – the area sensor camera shows a slightly better accuracy potential. However, the Scan 5000 allows recognizing very small details due to its high resolution and is therefore particularly suitable for applications, where image interpretation and interactive measurement is required.

Figure 1. Line scanning camera Pentacon Scan 5000

# 1. CAMERA PENTACON SCAN 5000

## 1.1 Macro Scanning Principle

Macro scanning has been introduced in digital camera technology as an option to achieve high resolution digital imagery already more than 20 years ago. Concepts based on a linear array sensor scanning the image plane one-dimensionally or a small-format array sensor scanning the image plane two-dimensionally (e.g. Luhmann and Wester-Ebbinghaus, 1986) have been developed by several manufacturers and used in photogrammetric applications. With the recent growth of CCD and CMOS sensor format and their dramatic price drop, the necessity of macro-scanning techniques has been reduced. Nevertheless, they still offer a much higher resolution potential than high resolution full frame sensor cameras at affordable prices.

The basic concept of a linear array sensor macro scanning camera is shown in Figure 2. While the resolution perpendicular to the scan direction is defined by the pixel size and pixel number on the CCD-line, the resolution in scan direction is determined by the scanning speed and the scan increment of the drive mechanism. Moreover, equipped with a three line RGB linear array sensor this principle offers the potential to record true RGB imagery without colour interpolation.

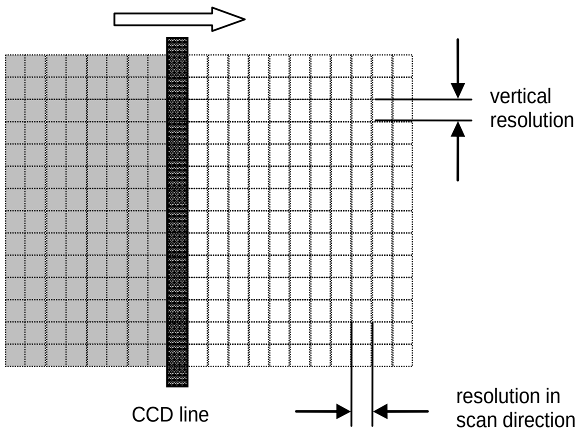


Figure 2. Principle of line scanning cameras

This recording principle has also disadvantages. The high resolution in the image is achieved by long image recording times, since the exposure time has to be applied for each image column. The recording time may take several minutes at poor lighting conditions. As a consequence, moving objects can not be recorded, and it is essential to use the camera on a stable tripod. Moreover, the geometric precision is limited by moving mechanical parts inside the camera and effects of vibrations. Due to the recording principle, another challenge can be seen is proper object illumination. It is not possible to use a flashlight. Changing light during image recording may lead to undesirable variations of the brightness in the image.

## 1.2 Macro Scanning Cameras

Table 1 gives a short overview on commercially available macro-scanning cameras and camera backs. While the overview does not claim to be complete, it shows the resolution potential of this type of camera. Relatively new on the market is the Pentacon Scan 5000, which is presented and tested in this paper.

| Line scanning camera backs | |
|---|---|
| Rollei Gamma S12 | 3 500 × 3 500 Pixel |
| Rollei ScanPack | 5 850 × 5 000 Pixel |
| Anagramm picture gate 8000 daguerre | 7 250 × 6 000 Pixel |
| Anagramm picture gate 8000 david | 17 400 × 14 400 Pixel |
| Line scanning cameras (stand-alone) | |
| Pentacon Scan 3000 | 5 363 × 5 363 Pixel |
| Pentacon Scan 5000 | 12 000 × 8 192 Pixel |

Table 1. Examples of line scanning cameras and camera backs

The principle of a linear array macro scanning camera is related to the operating principle of rotating line cameras (digital panoramic cameras), and their resolution potential is also comparable. But in digital panoramic cameras, the linear sensor does not move with respect to the camera, as the whole camera rotates around a vertical rotation axis. The horizontal field of view is therefore not limited by the lens, and a full 360° field of view around the camera position can be recorded (Schneider & Maas 2004).

## 1.3 Pentacon Scan 5000 Technical Data

The investigations described in this paper are carried out with the linear array macro scanning camera Scan 5000, made by Pentacon (Germany). This camera was released 2002 and offers a 94 megapixel image format. Some specifications are summarized in Table 2.

| | |
|---|---|
| Lens adapter | Nikon, Schneider-Kreuznach, Rodenstock, et al. |
| Sensor | Tri-linear CCD line with 3 × 8192 pixel |
| Radiometric resolution | 3 × 12 Bit |
| Scan area | 43,0 × 28,7 mm |
| Scan duration | 40 seconds to 3 minutes |
| File size | 288 MB @ 24 bit |
| Connection and power supply | FireWire (IEEE 1394) |
| Controlling software | Scansoftware SilverFast Ai |

Table 2. Specifications of the Pentacon Scan 5000

## 1.4 Applications

Linear array macro scanning cameras are often used to digitise large originals, such as maps or paintings. Other applications are the conservation of evidence in the field of criminology, product photography in advertising, photography in medical tasks and the recording of originals in museums and archives. In photogrammetric applications, such as architectural photogrammetry for documentation purposes of historical facades, line scanning systems may also be considered an interesting option.

## 2. ACCURACY INVESTIGATIONS

In photogrammetric practice one has to differentiate between the resolution and the precision of a measurement system. In many cases, e.g. at interactive measurements of natural object points, a high resolution is a precondition for the geometric accuracy of the final result of data processing. In other applications such as industrial 3D coordinate measurement tasks, the precision potential is largely determined by the potential of subpixel accuracy image analysis techniques. On the other hand, a high resolution does not automatically mean a high accuracy, since further factors, such as the calibration and the geometric stability of the camera as well as the correctness of the mathematical model, affect the accuracy potential. This applies especially to imaging systems with moving elements. For this reason several investigations were carried out in order to analyse the accuracy potential of the Scan 5000.

### 2.1 Self Calibration

In order to assess the accuracy of this macro scanning system, an image block of a test field was imaged in a camera self-calibration scheme according to (Godding, 1993) and analysed in a bundle block adjustment. The dimension of this test field is ca. 1 m² and it consists of 150 signalised points (Figure 3). The recording of 12 images (8 convergent and 4 90°-rolled images) took approximately 1 hour. The resulting standard deviation of the unit weight is $\sigma_0$ = 0.51 µm. This corresponds to 1/7 of the pixel size and a relative precision of 1 : 70’000 related to the sensor format. The average standard deviation of object point coordinates obtained from free bundle block adjustment was $RMS_X = RMS_Z$ = 7 µm (lateral point precision 1 : 150’000 of object dimension) and $RMS_Y$ = 20 µm (depth direction).

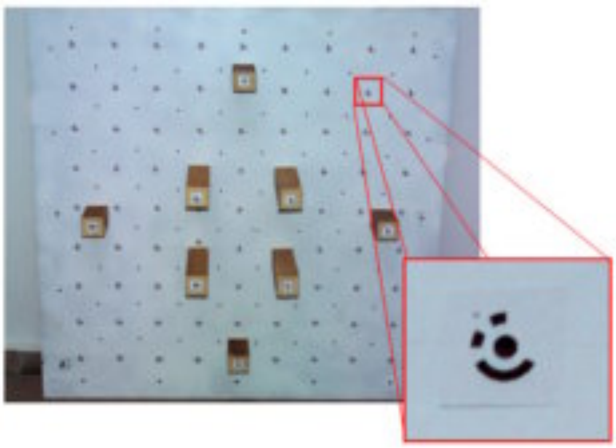

Figure 3. Test field (110 × 110 cm, 150 signalised points)

Parameters to compensate the radial-symmetric and tangential lens distortion were considered in the bundle block adjustment step by step. No significant distortion of the lens (Nikkor 50 mm) was detected. The affinity and shear of the image coordinate system are of particular interest at this analysis. Due to the recording principle of a moving sensor line the image directions (x’, y’) may have an unequal scale (affinity) caused by an imprecise adjustment between scanning speed and integration frequency, which leads to a compression or dilation of the image content. Also non-perpendicular image coordinate axes (shear) may be suspected as a consequence of the tracking system of the sensor line. Both parameters were not significant, showing the high geometric-mechanical quality of the camera.

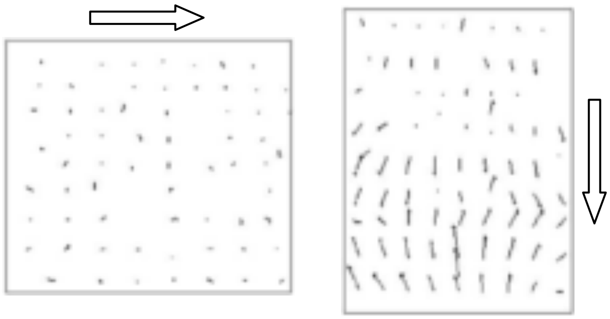

Figure 4. Residuals of image coordinates – image with horizontal (left) and vertical (right) moving sensor

In addition, the resulting residuals of image coordinates in each image were analysed. There were significant differences noticeable between images recorded with a horizontal camera orientation and a 90° rotated orientation, where the CCD line moves vertically (Figure 4). While the residuals in the horizontal images seem to be distributed randomly, the vertical images show systematic vertical residuals in the order of magnitude of 1 pixel. This effect may be a sign of a mechanical clearance within the tracking system of the CCD sensor, which has to be clarified within the scope of further investigations. Rotating the test field instead of the camera in order to avoid this effect may be an option in a laboratory test using a small calibration object, but is not a realistic option for simultaneous self-calibration in typical application fields of the camera.

### 2.2 Comparison with the Kodak DCS Pro 14n

In order to compare the accuracy potential of the Pentacon Scan 5000 with that of current full frame array sensor cameras, the same test field was recorded in the same manner with the digital 14 megapixel camera Kodak DCS Pro 14n and also analysed via self-calibrating bundle adjustment. This camera is currently one of those small format SLR cameras with the highest resolution (Peipe & Quifeng, 2004).

| Pentacon Scan 5000 | Kodak DCS Pro 14n |
|---|---|
|  |  |
| Tri-linear CCD line<br>„Scanning Camera“ | CMOS array sensor<br>„One Shot Camera“ |
| 94 mega pixel<br>(true RGB) | 14 megapixel<br>(RGB from Bayer-pattern) |
| Pixel size: 3,5 µm | Pixel size: 8 µm |

Table 3. Comparison of line scanning and array sensor cameras

A visual comparison between the different resolutions of both cameras is shown in Figure 5. Both map segments were captured from 3 m distance using the same lens and almost the same field of view. The difference is even more evident in the colour image, since the colour information is generated without any interpolation by the Pentacon Scan 5000.

| Pentacon Scan 5000 | Kodak DCS Pro 14n |
|---|---|
|  |  |

Figure 5. Differences of the resolution

Unlike the stunning difference in resolution, the accuracy parameters of both cameras resulting from the bundle block adjustment are at a comparable level (Table 4).

| Pentacon Scan 5000 | Kodak DCS Pro 14n |
|---|---|
| $\sigma_0$ = 0.51 µm (ca. 1 / 7 pixel, 1 : 70 000 of sensor format) | $\sigma_0$ = 0.38 µm (ca. 1 / 20 pixel, 1 : 95 000 of sensor format) |
| Object coordinates (free bundle block adjustment): | |
| $RMS_{Lateral}$ = 7 µm<br>$RMS_{Depth}$ = 20 µm | $RMS_{Lateral}$ = 5 µm<br>$RMS_{Depth}$ = 9 µm |

Table 4. Bundle block adjustment results of both cameras

As expected, the superiority of the linear array macro scanning camera in resolution can not be translated into an equivalent superiority in precision. This may be traced back to internal effects (e.g. limited mechanical tracking accuracy of the sensor) and external effects (e.g. vibrations, transmitted through the underground and tripod) during to the long recording times in comparison to a one-shot camera.

## 3. PHOTOGRAMMETRIC POTENTIAL

Despite the obvious (and expectable) non-ability to translate the superiority in resolution into a superiority in precision, the test results can be considered rather good, since the geometric precision accuracy of the Pentacon Scan 5000 is much better than the interactive image measurement precision. The precision potential of the camera is fully appropriate regarding the typical application field of the camera, where automatic subpixel accuracy image measurement techniques do usually not play a major role. If image points have to be measured interactively, the high resolution is more important for the accuracy, since it is hardly possible to achieve an image measurement accuracy of 1/7 pixel in interactive measurements. This camera is rather suitable for applications, where high requirements on colour authenticity and perceptibility of details have to be complied, for example at the digitisation of large format originals in museums and archives.

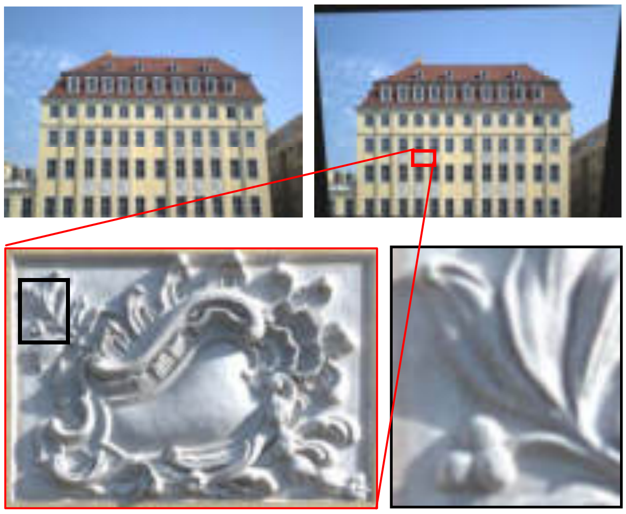

Figure 6. Architectural photogrammetry – digital rectification of a facade and resolution potential

Traditional photogrammetric tasks, where the camera presents an interesting alternative to conventional methods, are large-scale documentations in indoor applications. In addition, the camera can be used in the field of architectural photogrammetry, where resolution is often more important than accuracy, e.g. at the documentation or mapping of cracks at historical facades (cp. Figure 6). In this application the line scanning camera competes against analogue large format cameras, and it offers all the advantages of digital image recording (e.g. assessment of the image quality in situ, no need of image developing, online processing potential). Disadvantages of the camera can mainly be seen in the long image recording times, enforcing the use of a stable tripod and introducing undesired effects in situation with moving objects and changing illumination conditions.


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