

## DMC - Practical Experiences and Photogrammetric System Performance

CHRISTOPH DÖRSTEL, Z/I Imaging, Aalen

### ABSTRACT

The digital mapping camera (DMC) from Z/I Imaging is currently introduced into the market. When talking about modern digital mapping cameras, user looks to the airborne component as well as to the complete digital end-to-end workflow. Developing the DMC, Z/I has taken care of the complete workflow and introduced a system consisting of components for mission planning, mission control, the main camera module, mission reporting and data post processing.

During the final certification phase of the DMC camera system, thousands of images were taken to assess the whole system. The camera passed this test where the main focus was put on its ease of use and simple workflow, accuracy aspects of the image data, and long time stability and reliability. Data taken during these tests were processed using TerraShare (Z/I Imaging Data Management and Distribution) through the whole ImageStation enterprise workflow.

This paper highlights some of the experiences we gathered through the camera certification phase. Accuracy aspects of the digital data collected with the DMC system are shown at the main steps of aerial triangulation and stereo compilation.

### 1. INTRODUCTION

Beginning of this year Z/I Imaging has manufactured the first DMC (Digital Mapping Camera) under series production conditions. Goal of the DMC development was to transfer the photogrammetric capabilities of the analogue film cameras like the RMK-TOP to the digital technique.

Ideally, a single chip with an appropriate size and resolution should be used, but such a largeformat chip is not available yet for technological and economical reasons. Since a large field of view is mandatory in aerial photogrammetry due to the high accuracy requirements and by economical reasons, several CCD's can be combined to deliver the large ground coverage. DMC uses a combination of 8 cameras where the 4 precisely calibrated high resolution pan camera heads (Dörstel, Jacobsen Stallmann 2003) are combined into one virtual image, with central perspective as shown in Figure 1.

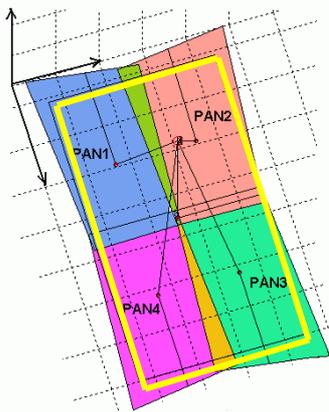


Figure 1: Footprint of 4 pan images projected into the virtual image (yellow)

The resulting accuracy of such a virtual image was under discussion for than three years. With several theoretical (Tang, Dörstel, et. al. 2000) and practical investigations (Zeitler, Dörstel, Jacobsen 2002) the concept was proofed (Heier, Hinz 2002).

The DMC principle design is based on up-to-date sensor technology in combination with image processing techniques partly known from aerial

photogrammetry and remote sensing (Hinz 1999, Hinz, Dörstel, et. al. 2000, Hinz, Dörstel, et. al. 2001).

This paper presents triangulation results of the latest test flights. A brief introduction of the test field and the photogrammetric blocks are followed by discussions on the aerotriangulation results and measurement accuracy from DMC stereo images is presented.

## 2. TEST AREA

The test field Elchingen, used by Z/I Imaging as its reference site, is located near by Aalen, Germany. At the end of the last year the original test field (Figure 2) was extended to include the Elchingen airport. Z/I Imaging often uses this test field for installing aerial cameras into aircrafts, for DMC calibration flights and for IMU calibration.

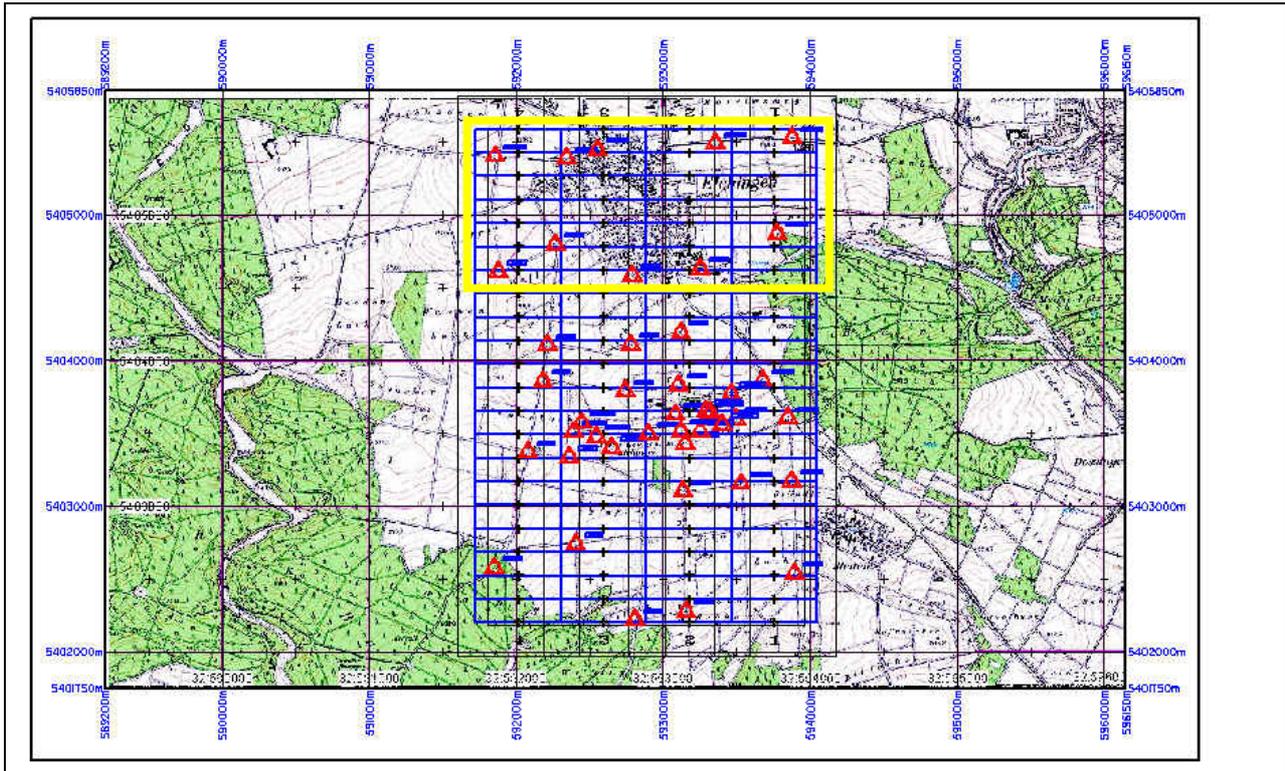


Figure 2: Test field Elchingen with footprints of images at 1:5000 / 600[m] altitude (blue) and footprints of images at 1:4000 / 460[m] altitude (yellow). The complete area (blue) was captured by flights at 1200[m] and 1800[m].

This test area was flown at several altitudes. Table 1 lists different flight configurations. The projects contain a series of typical scales used for ortho photo production, mapping and engineering projects.

Project	Base [m]	Height[m]	Base/Height	Image Scale	GSD [m]	endlap
EL4	141.3	460	0.3071	1:4000	0.046	60%
EL5	161.3	600	0.2688	1:5000	0.060	65%
EL10	184.3	1200	0.1536	1:10000	0.120	80%
EL15	276.5	1800	0.1536	1:15000	0.180	80%

Table 1 : Flight configuration at Elchingen test field

These projects were planned with 30% sidelap for aircrafts and a speed of about 130knt to 160knt. After the flights the MDR's (Misson Data Recorder) were transferred to the Z/I office in Aalen and

the digital images were processed. It took about 8 ½ hours to post process the data of these four projects.

Following, in ISAT (ImageStation Aerial Triangulation) the block was defined and point matching started. The resulting sigma0 (Table 2) indicates successful processing and good interior block stability.

Project	No. of Images	Matching per image [sec]	Aerotriangulation with relative adjustment	
			Sigma0 [µm]	RMS image points [µm]
EL4	30	18	1.7	1.7
EL5	88	31	1.9	2.0
EL10	40	28	1.6	1.4
EL15	13	24	1.4	1.6

Table 2: Results of point matching with ISAT

### 3. RESULTS

This section describes the photogrammetric results of these tests. First the aerotriangulation results are discussed based on the expected accuracies. Then, an assessment of the measurement accuracy of the DMC stereo models is given.

#### 3.1. Aerotriangulation

To assess the quality of an aerotriangulation, we have to take various factors into account. The accuracy is e.g. influenced by the block configuration, the control point quality and point configuration. A clear justification of a good AT result is not always easy but lot of literature and experience helps to come up with some good criteria.

To evaluate the results reached by aerotriangulation we have to describe the expected accuracy. According to Kraus (1984) we can compute the expected planar accuracy with:

$$\sigma X = \sigma Y = \sigma C * \text{image scale}$$

where  $\sigma C$  represents the image coordinate accuracy. For blocks from analogue cameras, experience has shown that for a regular block with well distributed control points we can assume  $\sigma C = 5[\mu\text{m}]$  in the image space. However, the potential accuracy of DMC is higher and can theoretically be computed by

$$\sigma X = \sigma Y = \sigma_{\text{Block}} * \text{image scale}$$

but, just if the block configuration, point definition and coordinate reference is ideal. For our investigation we use  $\sigma C = 5[\mu\text{m}]$  to compute the expected accuracy and therewith taking the higher accuracy potential of DMC into account and there with compensate for some flaws in the point configuration.

The expected height accuracy can be computed with:

$$\sigma Z = \pm x\% h_g$$

From a practical point of view we can expect  $x = \pm 0.05\% h_g$  for the height accuracy of analogue cameras. Taking the b/H ratio of the DMC cameras into account it sounds fair to set the same expectation.

The results of the bundle block adjustment by ISAT are presented in Table 3.

Project	Image Scale	No. of Control	$h_g$ [m]	expected accuracy of object points [m]			computed accuracy of object points RMS Values [m]		
				$\sigma X$	$\sigma Y$	$\sigma Z$	$\sigma X$	$\sigma Y$	$\sigma Z$
EL4	1:4000	8	460	0.020	0.020	0.023	0.012	0.014	0.018
EL5	1:5000	34	600	0.025	0.025	0.030	0.023	0.025	0.034
EL10	1:10000	33	1200	0.050	0.050	0.060	0.031	0.031	0.043
EL15	1:15000	35	1800	0.075	0.075	0.090	0.041	0.036	0.029

Table 3: PhotoT, Bundle Block Adjustment results for DMC images

The results for the 1:15000 and 1:10000 scales are very good. The computed RMS values are significantly below the expectation, the computed RMS is better than a ½ of the maximum RMS. Same can be said for the 1:5000 and 1:4000 blocks, but looking to the RMS we can see that the block configuration was not ideal. For these blocks we had less than one control point per 4 base lengths which can be seen in the bad RMS value for Z.

Systematic effects could not be discovered, but as mentioned in Zeitler, Dörstel, Jakobsen (2002) non square pixels were computed for a former DMC. If we apply camera self calibration during bundle block adjustment we can improve the results of the AT to a further degree.

### 3.2. Stereo measurement accuracy

The final measurement accuracy is one of the most interesting issues for the practical use of the camera. To assess the measurement accuracy of objects several tests have been applied based on images we captured during the factory acceptance tests in Aalen. The test covers two topics, the planar and height measurement accuracy from DMC imagery. There for a series of images was taken over the well known Vaihingen test field maintained by the University of Stuttgart. The test field was flown at different altitudes. Table 4 lists the different configurations.

Project	Base [m]	Height[m]	Base/Height	Image Scale	GSD [m]	endlap
VA5	161.3	600	0.2688	1:5000	6.0	65%
VA6	193.5	720	0.2681	1:6000	7.2	65%
VA125	403.2	1500	0.2688	1 :12500	15.0	65%
VA20	645.1	2400	0.2688	1 :20000	24.0	65%

Table 4 : Flight configuration at Vaihingen test field

### 3.2.1. Planar measurement accuracy

According to Kraus (1986) the image coordinate accuracy is  $\sigma_C = \pm 8[\mu\text{m}]$  at signalized or well defined points. However, the measurement accuracy for natural points depends on object definition quality, which is high for man made objects (e.g. houses, manhole, ...) and reduces for natural objects (e.g. tree, field corner, ...). Further on we know from practical experience, that the setting quality of circular (manhole) objects is better than for edges (house corner). The following comparison uses  $\sigma_C = \pm 8[\mu\text{m}]$ , as we just measured well defined points.

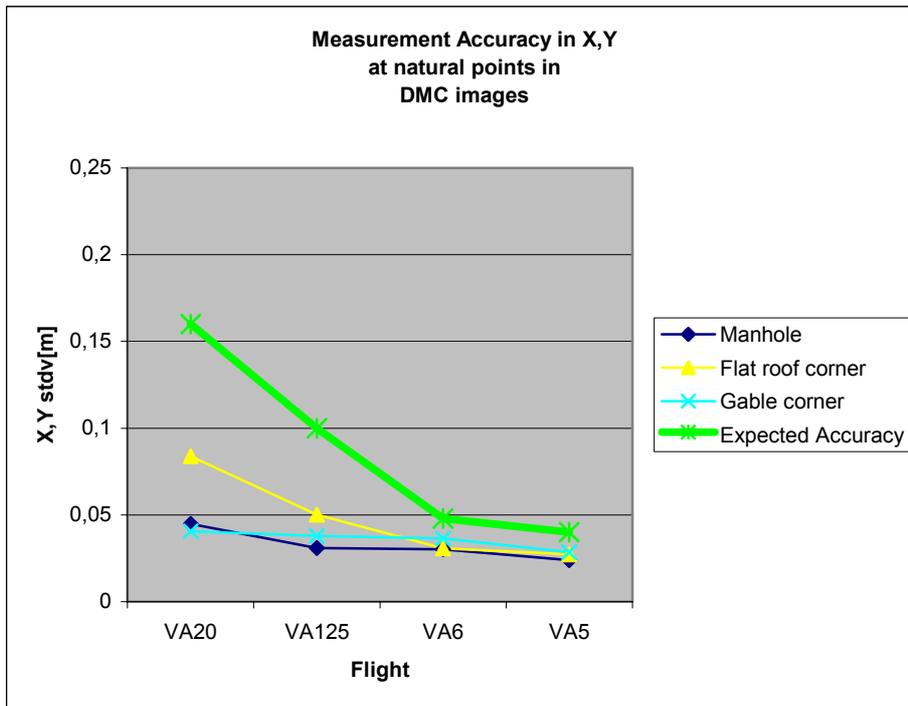


Figure 3: Coordinate measurement accuracy at natural points compared vs. expected coordinate accuracy at  $8[\mu\text{m}]$  coordinate measurement accuracy in the image

In Figure 3 the expected accuracy is computed with:

$$\sigma_X = \sigma_C * \text{image scale}$$

Each point was measured 10 times. After each measurement the floating mark was moved to the next point so we can compute the accuracy of the point measurements.

In Figure 3 we can see that the planar measurement accuracy in DMC images is below the expectation of  $\pm 8[\mu\text{m}]$ . For the 1:5000 flight the expected coordinate accuracy is about 0.04[m], the reached accuracy at the man hole is 0.025[m].

For practical use we can assume that the coordinate measurement accuracy can be computed using  $\sigma_C = \pm 4-5[\mu\text{m}]$  for well defined object points.

### 3.2.2. Height measurement accuracy

To assess the reachable height accuracy we measured different objects in a sequence of images taken at different altitudes. The expected accuracy is computed by

$$\sigma_Z = \pm 0.1\% h_g .$$

This value includes all influences from operator index to uncertainties in object definition. The result (Figure 4) shows that the expected height accuracy is reached easily with DMC images. For the measurements in the garden a decreased accuracy is reached. According to Kraus the height accuracy for field is 0.1 – 0.2[m].

Therefore we can draw the conclusion that for practical use of the DMC we can assume that a height accuracy of 0.08‰  $h_g$  can be reached for well defined points. This is comparable to the accuracy reachable with a RMK TOP.

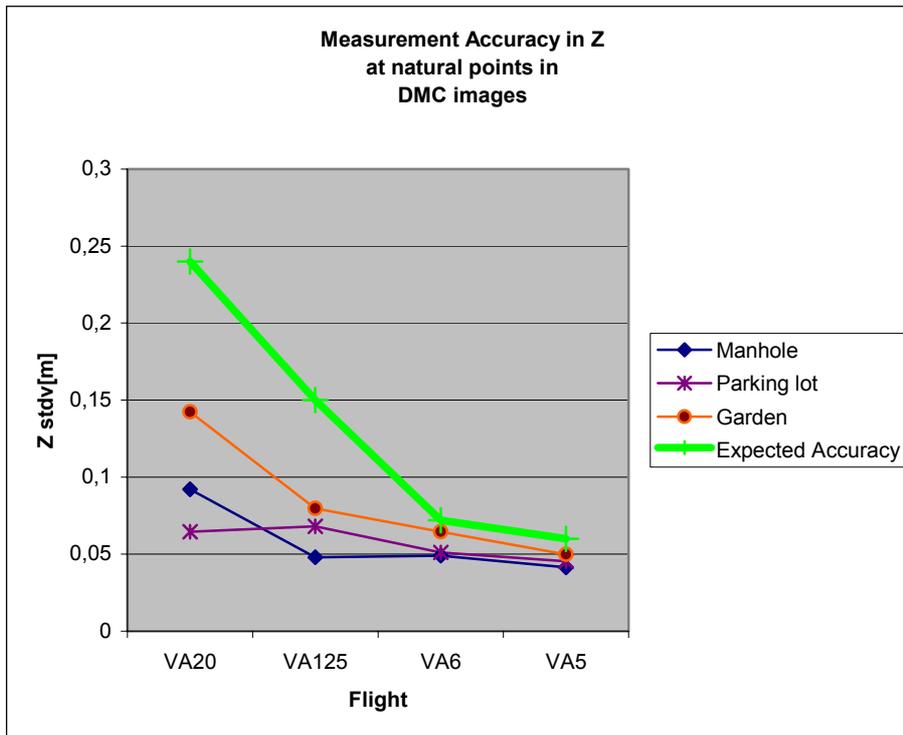


Figure 4: Height measurement accuracy at natural points, with expected accuracy of 0.1‰ of  $h_g$

#### 4. CONCLUSION

The tests have shown that the overall accuracy of a DMC is comparable with conventional cameras. The aerotriangulation results indicate that the planar accuracy is superior and the height accuracy is within the expectations. Especially these tests emphasized that the height accuracy of a DMC is comparable to an RMK TOP 30 and therefore the lower b/H-ratio of the DMC can be fully compensated by the improved image quality and the stable image geometry. With this test we figured out that the accuracy of the aerotriangulation is:

$$\begin{aligned} \sigma X_{AT(DMC)} = \sigma Y_{AT(DMC)} &< \pm 5[\mu\text{m}] * \text{image scale} \\ \sigma Z_{AT(DMC)} &< \pm 0.05\text{‰ } h_g \end{aligned}$$

However, the potential accuracy of the DMC system is better than the values reached. This is indicated by the very good sigma0 values of the bundle block adjustment. In future an optimized control point configuration will help to reach better accuracies.

In a stereo model it has been shown that the accuracy of the repeatability of point measurements can be computed with:

$$\begin{aligned}\sigma X_{\text{stereo(DMC)}} = Y_{\text{stereo(DMC)}} &< \pm 8[\mu\text{m}] * \text{image scale} \\ \sigma Z_{\text{stereo(DMC)}} &< \pm 0.08\text{‰ } h_g\end{aligned}$$

The measurement accuracy was demonstrated in the object space but at this point in time we did not check at independent check points. This is currently investigated and will be published soon. Further test flights and experiences from our first customer will continue to help us to evaluate the overall DMC system performance.

## 5. REFERENCES

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