MAPPING USING HIGH-RESOLUTION AND STEREOSCOPIC SPACE IMAGERY OF MOMS-02

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ABSTRACT:

Due to its high resolution and the along-track stereoscopy capability the electro-optical scanner MOMS-02 is considered as possible data source for creating and revising topographical databases at medium scales. The essential aspects concerning its actual suitability - i.e., operational features, geometrical accuracies as well as the inherent information content - are examined within this contribution.

1 INTRODUCTION

The status of a world-wide and up-to-date coverage with spatial databases in digital or analogue form is not satisfying yet. One longterm solution for this problem could be the use of space-borne electro-optical scanners as an alternative data source. At this, one of the latest and most promising sensor developments is the German Modular Opto-electronic Multispectral Stereo Scanner in its second version (MOMS-02) which was sucessfully flown for experimental purposes during des D2-Spacelab mission in 1993 (MOMS-02/D2) and which shall be employed for a pre-operational use from 1996 on when it will be put on the "Priroda"-module of the Russian MIR-station (MOMS-02/P).

The MOMS-02 system is described in detail by Seige and Meißner (1993). It offers two major advantages which make it a valueable data source for photogrammetrical and cartographical applications. Firstly, it has ground pixel sizes of 4.5 m (MOMS-02/D2) or 6 m (MOMS-02/P) for one High-Resolution (HR) nadir looking panchromatic channel and 13.5 m (D2) or 18 m (P) for the other panchromatic and four multispectral channels. Secondly, the existence of two tilted panchromatic channels - forward (FW) and backward (BW) looking with angles of plus and minus 21.4°, resp. - in combination with the HR-channel allows for a up to three-fold along-track stereoscopy. At present these features are unique within in the field of civilian space sensors. In comparison, the operational SPOT-system offers ground pixels down to 10 m and across-track stereoscopy only.

Evaluations of the MOMS-02 data are performed by a science team which consists of a couple of German university institutes. Research aspects within the digital photogrammetrical group are the orientation determination by means of orbit modelling (Ohlhof, 1995), automatic matching and the derivation of Digital Elevation Models (Schneider and Hahn, 1995) and the evaluation of the cartographical potential as well as the actual creation and revision of spatial databases (Schiewe, 1995).

This contribution will focus only on the data potential of MOMS-02 in terms of operational aspects (chapter 2), geometrical accuracies (chapter 3) and the inherent information content (chapter 4).

2 OPERATIONAL ASPECTS

The suitability of a system concerning its operational aspects can be inspected in terms of the spatial and temporal coverage.

The *spatial coverage* describes the position and extent of data recordings. Regarding the accessible positions MOMS-02/D2 was limited to the low inclination of ± 28.5° of the Space Shuttle carrier. MOMS-02/P will be able to cover areas up to latitudes of ± 51.6° which is still less compared to other systems like SPOT or Landsat TM which operate in sun-synchronous orbits. - Generally the recorded swath width serves as a measure for the spatial extent. Due to data recording and transmission reasons all MOMS-02 channels cannot be operated simultaneously. The resulting operation modes for the Priroda-mission are listed in table 1. The graphical representation of the ground pixel size versus the swath width in comparison to other operational and proposed sensors (figure 1) elucidates that especially with the MOMS-02 stereo mode A the emphasis is laid on a comparable good swath width.

Mode	Multisp. channels				Pan. channels			Swath width
	B	G	R	IR	HR	FW	BW	
A					■	■	■	50 km
B	■	■	■	■				105 km
C		■	■	■	■			58(36) km
D	■			■		■	■	105 km

Table 1: Operation modes of MOMS-02/P

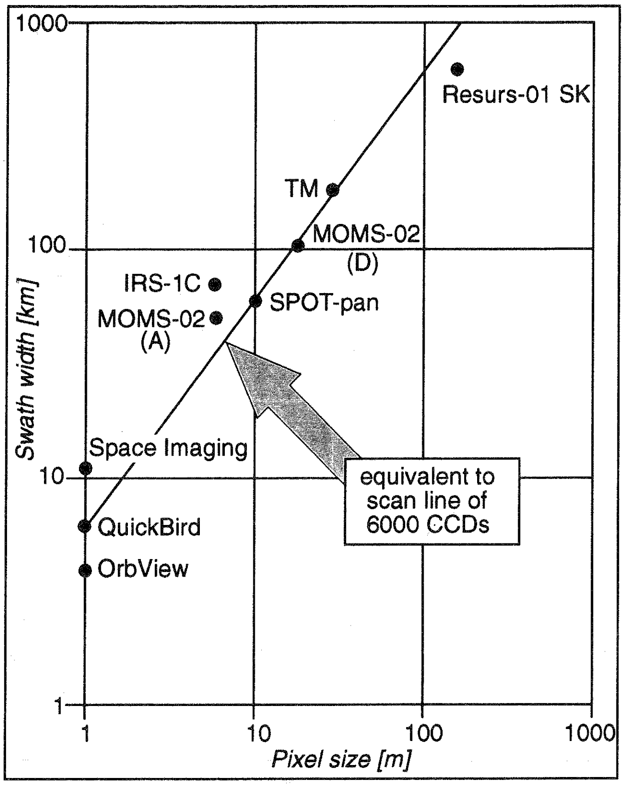

Figure 1: Ground pixel size versus swath width of (pre-) operational and proposed sensors (logarithmic scale)

These numbers can be illustrated even better with the necessary number of scenes for creating a map sheet at a certain scale and extent. Assuming a target scale of 1 : 25 000 and a sheet of 1m • 1m one or two HR-MOMS-02 scenes are needed, whereas 25 scenes of QuickBird or 49 scenes of OrbView have to be taken into account which lead to the conclusion that these proposed 1-m-US-systems are not cost-effective at those scales.

The *temporal coverage* describes the desired point as well as the frequency of data acquisition. Again, due to its experimental or pre-operational character MOMS-02 possesses limited features. MOMS-02-02/P is planned to stay in space for 18 months whereby swaths next to each other have a track difference of three days. The recording time will be reduced because it has to be shared with other sensors onboard the MIR-station.

Summarizing this, it can be stated that the MOMS-02-instrument itself offers a good coverage for medium scale mapping purposes especially in terms of the spatial extent. The overall mission parameters have yet to be adopted for a full operational mission which is envisaged for the year 2000 (MOMS-03 mission).

3 GEOMETRICAL ASPECTS

Mapping at certain scales demands for appropriate geometrical accuracies of the data source. After describing these demands (section 3.1) the strategy for a practical evaluation will be outlined (section 3.2) and results will be presented considering the impact of various input parameters (section 3.3).

3.1 Geometrical demands

There are no world-wide accepted rules for horizontal and vertical accuracies for topographical databases so that the following values only reflect an average. According to that, for the horizontal accuracy a value of 0.3 mm times the target map scale should be achieved, e.g. 7.5 m at a scale of 1 : 25 000. The measure for the vertical accuracy amounts to 0.3 times the contour interval which itself depends on the terrain and the specific application. Assuming typical intervals in the range of 10 to 20 m the accuracy should be in the order of 3 to 6 m.

3.2 Methodology

The general strategy for a practical evaluation of the geometrical accuracy is to compare coordinates of distinct control points as derived from MOMS-02 imagery with given reference coordinates.

Therefore, *control points* are measured digitally within the MOMS-02 images in monoscopic or stereoscopic mode. Stereoscopic measurements are performed by means of a digital photogrammetrical workstation using the Crystal Eyes principle (Siebe et.al., 1992). For this, the oblique channels FW and BW can be used as well as a combination of the high resolution channel (HR) and one of the oblique channels which have have to be brought to the same scale.

Reference coordinates of the control points have been obtained by digitizing from maps, ranging from 1 : 5 000 (test site Harare, Zimbabawe) over 1 : 10 000 (orthoimage maps of Dubai-City, United Arab Emirates) to 1 : 50 000 (Pasajes, Bolivia). More precise coordinates were not available for these test sites.

In order to compare the coordinates a *transformation equation* has to be found. In our case this is done by a relatively cost and time consuming Ground Control Point (GCP)- method. Either the strict geometrical model - central projection within the scan line and parallel projection in flight direction - is applied using stereoscopic imagery, or simple polynomials of first or second order are used which are necessary if no stereo imagery is available.

In the first case the program BLASPO is used which performs bundle adjustments for line scanners like SPOT or MOMS-02 (Jacobsen, 1994). It utilizes neither actual and precise orbit data nor automatically matched conjugate points, but standard orbit values as well as additional parameters for the affinity and angular affinity. Because the mathematical model is based on the transformation between two strictly orthogonal coordinate systems the control points have eventually to be transformed from a map projection (like UTM) into a local tangential system. By theory one yields one set of exterior orientation parameters for every single scan line, but due to the high correlation only every n-th line (n = 100 ... 10 000) has to be considered.

The resulting transformation equation is then applied to some Independent Control Points (ICPs) and compared to reference coordinates. Or an entirely rectified image is produced, the ICPs are measured within this image and compared with the reference. Then the resulting residuals serve as a measure for the desired geometrical accuracy.

3.3 Practical results

Several tests using MOMS-02 imagery regarding the dependency on different test sites, different numbers of GCPs, different pixel measurement techniques as well as different transformation models have been conducted. The used data sets of Dubai (U.A.E.), Harare (Zimbabwe) and Pasajes (Bolivia) show various drawbacks so that each aspect has to be handled separetely without the possibility for an absolute comparison.

3.3.1 Test sites: Examinations on different test sites even in one single datatake can lead to inhomogenious results due to varying image or topography contrast, different target qualities (e.g., road crossings vs. hill tops), changed weather conditions or unequally accurate reference material. Table 2 compares three sub-scenes over Dubai whereby the object coordinates of the GCPs have always been taken from the same source. There is a continous decrease in accuracy from sub-scene A ("City Centre": good contrast, narrow road crossings as targets, stereo impression possible) over B ("Al Jumayrah": low contrast due to sensor problems, road-crossings) towards C ("Bida Saif": very low contrast, only some very wide road crossings).

Variable: Test site	**Result:** ICP-residuals		
	sx	sy	sz
A: Best contrast & targets	3.3 m	4.6 m	6.1 m
B: Weak contrast	3.9 m	5.3 m	7.5 m
C: Poor contrast & , targets	10.0 m	7.6 m	13.4 m
Constants: Pixel sizes = 4.5 m & 13.5 m / No. of GCPs (ICPs) = 7 (7) / Measurement = stereo / Transformation = collinearity / Reference = 1 : 10 000			

Table 2: Influence of different test sites

Comparing the test sites Dubai and Harare - both having good image contrast - by using polynomial transformations based on the same number of GCPs and ICPs yields differences in the planimetric residuals in the order of 0.5 to 1.0 m in favour of the Dubai data set. This leads to the conclusion that the reference material of Dubai (not generalized orthoimage maps at 1 : 10 000) is superior to that of Harare (combination of line maps at 1 : 5 000 and 1 : 25 000).

3.3.2 Number of GCPs: The number of used GCPs affects the reliability of the adjustment process. Experiences with MOMS-02 imagery show that about 10 points per scene is a sufficient measure. As table 3 indicates, also the minimum number of 4 points for the specific transformation model (Jacobsen, 1994) will yield acceptable results if well known and measured points are used.

Variable: No. of GCPs	**Result:** ICP-residuals		
	sx	sy	sz
24	3.7 m	3.9 m	4.7 m
15	4.3 m	3.5 m	4.2 m
7	3.8 m	3.4 m	4.0 m
4	4.0 m	3.6 m	4.7 m
Constants: Test site = Dubai-A / Reference = 1 : 10 000 / Pixel sizes = 4.5 m & 13.5 m / No. of ICPs = 26 / Measurement = stereo / Transformation = collinearity.			

Table 3: Influence of different numbers of GCPs

3.3.3 Pixel measurement techniques: Due to the along-track stereoscopic capabilites MOMS-02 data are suitable for deriving three-dimensional object information. Table 4 shows that there is a significant increase in accuracy - especially in the vertical component - if the incoming image coordinates are measured in stereoscopic rather than in monoscopic mode because the pointing accuracy is improved.

Variable: Measurement	**Result:** ICP-residuals		
	sx	sy	sz
Mono	4.6 m	4.4 m	10.9 m
Stereo	4.2 m	3.6 m	4.5 m
Constants: Test site = Dubai-A / Pixel sizes = 4.5 & 13.5 m / Reference = 1:10 000 / No. of GCPs (ICPs) = 25 (30) / Transformation = collinearity			

Table 4: Influence of different measurement techniques

Applying an interactive stereo measurement on-screen it has been found that although a multi-resolution combination of the HR-channel and the three-times enlarged channel FW (or BW) decreases the base-to-height-ratio by factor 2, at the same time the pointing accuracy is improved - theoretically by factor 3 - due to the use of high resolution data. In fact, the human eyes are so flexible that they neglect blurring effects coming from the low-resolution image.

Measurements within the Pasajes data set confirm these experiences whereby now due to the lack of appropriate absolute reference material the standard deviation of the relative orientation (s_{rel}) of the corresponding stereo partners serves as the accuracy measure (table 5). This value is based upon an overdetermination of measured conjugate points and is transformed from pixel into corresponding ground values. Both the multi-resolution and the single-resolution approaches show nearly the same relative accuracy of about 0.9 pixel which gives evidence about the same relative pointing accuracy. With that the absolute accuracy can be improved by factor 3 if the multi-resolution method with the HR-channel is used. - From table 5 one can also conclude that the image quality of the

Pasajes data set is rather poor compared to that of Dubai.

Test site	Variables			Result: s_{rel}	
	Channels (scale factors)		Pixel size	pixel	ground
Pasajes	BW (•1)	FW (•1)	13.5 m	0.94	12.7 m
	HR (•1)	FW (•3)	4.5 m	0.87	3.9 m
Dubai-A	HR (•1)	FW (•3)	4.5 m	0.31	1.4 m

Tabelle 5: Influence of channel combinations on relative orientation via interactive stereo measurement

In order to take full advantage of the digital type of MOMS-02 data an automatic matching procedure - at least in order to derive conjugate points as input for the computation of an exterior orientation or a Digital Elevation Model (DEM) - is ingenious instead of interactive, manual measurements. The used matching method - including a point search based on a modified Förstner-operator with a following least-squares adjustment - is described in more detail by Wang (1994).

Table 6 elucidates that the combination of the FW- and BW-looking channels results in a significantly better relative orientation than the multi-resolution approaches. With the latter methods information is lost due to the interpolated scaling of one of the channels - either by enlarging one oblique channel to the size of the HR-channel or by reducing the HR-channel to the size of an oblique channel.

Test site	Variables			Result: s_{rel}	
	Channels (scale factors)		Pixel size	pixel	ground
Pasajes	BW (•1)	FW (•1)	13.5 m	0.11	1.5 m
	HR (•1)	FW (•3)	4.5 m	0.48	2.2 m
	HR (•$^1/_3$)	FW (•1)	13.5 m	0.16	2.2 m
Dubai-A	HR (•1)	FW (•3)	4.5 m	0.21	0.9 m
	HR (•$^1/_3$)	FW (•1)	13.5 m	0.08	1.1 m

Tabelle 6: Influence of channel combinations on relative orientation via automatic matching

By comparing corresponding values of tables 5 and 6 it is evident that automatic matching procedures are superior to interactive measurements in terms of the number of derived conjugate points and the achieved accuracy (at least by factor 1.5). Nevertheless, interactive measurements are still a necessary task for determining the absolute orientation.

3.3.4 Transformation models: As exspected, applying the strict transformation model of the collinearity equation within the scan line yields slightly better results than using just a polynomial rectification (table 7). But if no stereo imagery is available, polynomials have to be taken into account. This is the case for the test site Harare, which also shows relatively flat terrain and where we have found planimetric residuals in the range of 5 to 6 m whereby the degree of the applied polynomials was without importance.

Variable: Transformation	Pixel sizes	Measurement	**Result:** ICP-residuals		
			sx	sy	sz
Collinearity	4.5 m / 13.5 m	Stereo	4.2 m	3.6 m	4.5 m
Polynomial	4.5 m	Mono	4.8 m	5.7 m	-
Constants: Test site = Dubai-A / Reference = 1:10 000 / No. of GCPs (ICPs) = 25 (30)					

Table 7: Influence of different transformation models

3.3.5 Summary: Like for standard evaluations of aerial photography the object point accuracies obtained from MOMS-02 imagery depend on a variety of factors. To examine the potential of the sensor itself the best values can be inspected which have been obtained under "optimal" conditions.

Comparing these values with the demands as pointed out in section 3.1 it is evident that the horizontal accuracy of MOMS-02 data is suitable for target scales of 1 : 25 000 or even larger. Because no suitable reference material was available for test sites with varying terrain, only the probably too optimistic values for flat urban areas of Dubai and Harare can be taken into consideration. Nevertheless, even these values cannot always satisfy the high demands so that for some applications the quality standards have to be reduced.

It was shown that using multi-resolution imagery for manual stereo measurements can improve the accuracy while automatic matching methods prefer images of the same resolution (i.e., FW- and BW-channels). A matching solution which incorporates all three channels simultaneously could not be realized yet.

Further tests will be carried out during the MOMS-02/P mission for test sites in developed countries with highly accurate reference material.

4 INFORMATION CONTENT ASPECTS

The suitability of a system for topographical mapping with respect to the information content depends on a variety of ground-side factors like relief and contrast of the topography and of scanner-side factors like the spatial and spectral resolution or the capability to identify three-dimensional objects. Due to this bundle of factors and the different demands for different applications no general measures but only a variety of recommendations for a suitable input source can be defined, e.g. by Konecny (1995).

Practical investigations have been carried out by visually comparing radiometrically enhanced MOMS-02 imagery

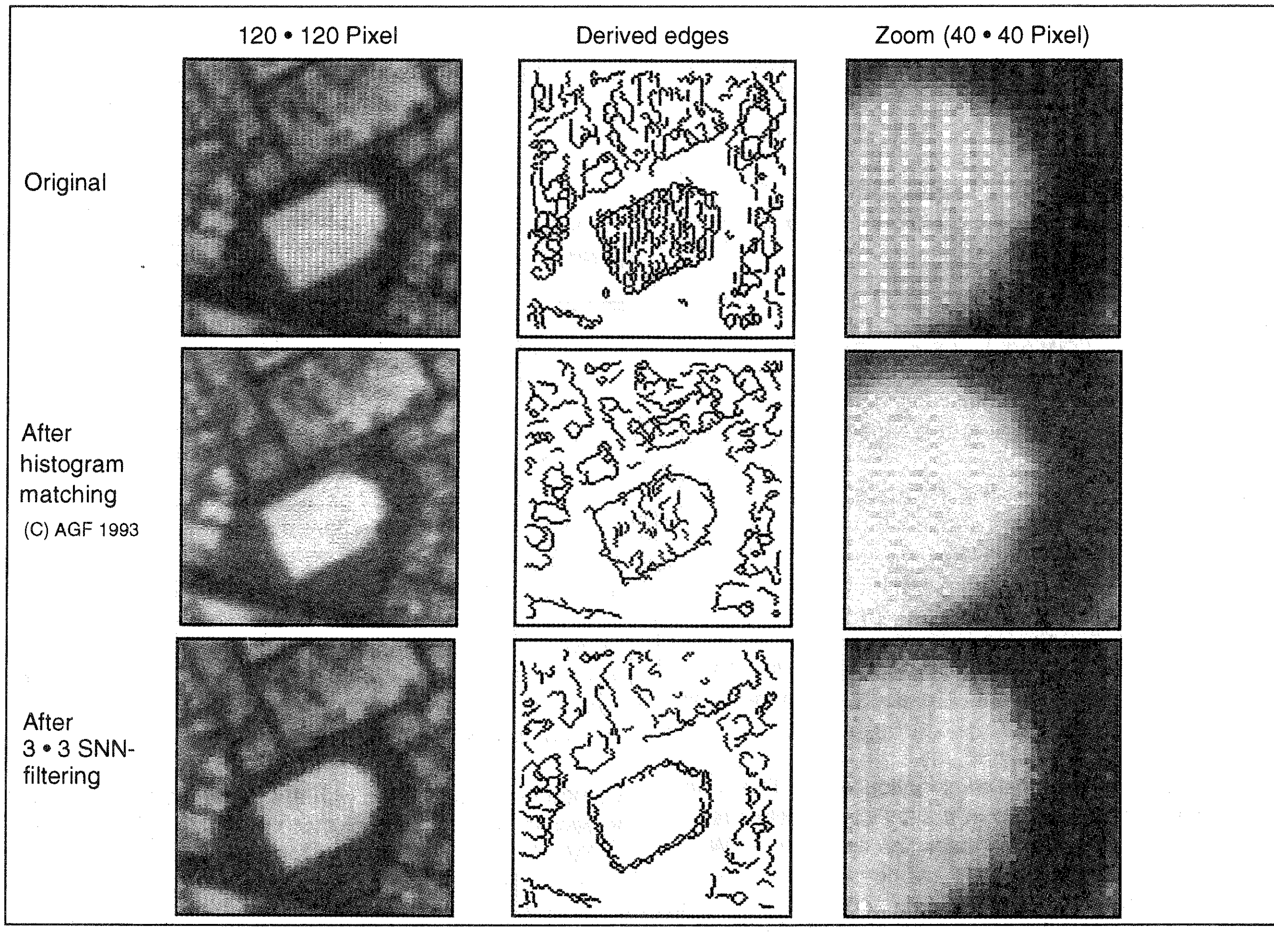

Figure 2: Radiometric operations for reducing striping characteristics by preserving edges, test site Dubai-City

with given reference material (like maps at various scales) or other data sources (like SPOT or Landsat TM). From that it can be generally stated that the extraction of topographical objects for mapping purposes by visual and interactive means is much more effective and reliable than by digital classification methods.

Radiometric operations applied to MOMS-02 images are necessary in order to remove or reduce systematic disturbancies like striping effects which have been detected in the case of MOMS-02/D2 (Berger and Kaufmann, 1995). This is done by means of a histogram matching algorithm or by applying the relatively fast 3•3, edge preserving Symmetrical Nearest Neighbour (SNN)- filter (Wang, 1994). Figure 2 demonstrates the strength of the latter method for an actually homogeneously bright area. Furthermore, desired features like edges can be enhanced for a following visual interpreation, e.g. by applying a Laplace-filter.

The *visual interpreation* and comparison of MOMS-02 test data confirmed the theoretical exspectations. Assuming typical contrast conditions, road and water networks can be extracted nearly completely. Of course, similar problems compared to the aerial photo interpretation occur if these objects are covered by other objects like trees. On the other hand it was found that in an urban area containing not so much contrast the derivation of building blocks or single houses smaller than 20 m • 20 m is difficult or impossible. Vice versa, a pixel size of about 2 m would be necessary for such tasks (Konecny, 1995).

Due to the better spatial resolution MOMS-02 offers a sharper demarcation of objects with less jaggies compared to SPOT or Landsat TM so that a more precise extraction of topographical features is facilitated (figure 3).

Finally, two features of the MOMS-02 system have been found very useful for the purpose of object extraction. Firstly, the combination of high-resolution with multispectral data (e.g. via an intermediate transformation into the Intensity-Hue-Saturation-color space) offers the operator a colored and enriched source. Of course, combinations with other data sources (e.g. Landsat TM, radar) are also possible. Secondly, the stereoscopic capability facilitates the identification of objects that stand out of their surrounding - not only mountains and hills, but also high buildings.

In summary, MOMS-02 data offer some progress compared to SPOT or Landsat TM with regard to the interpretability of objects which are necessary for mapping at medium scales. Depending on the specific application the capabilities can be sufficient - like in the case of our test sites for mapping at 1 : 25 000 - or not, if for example the extraction of single houses is needed.

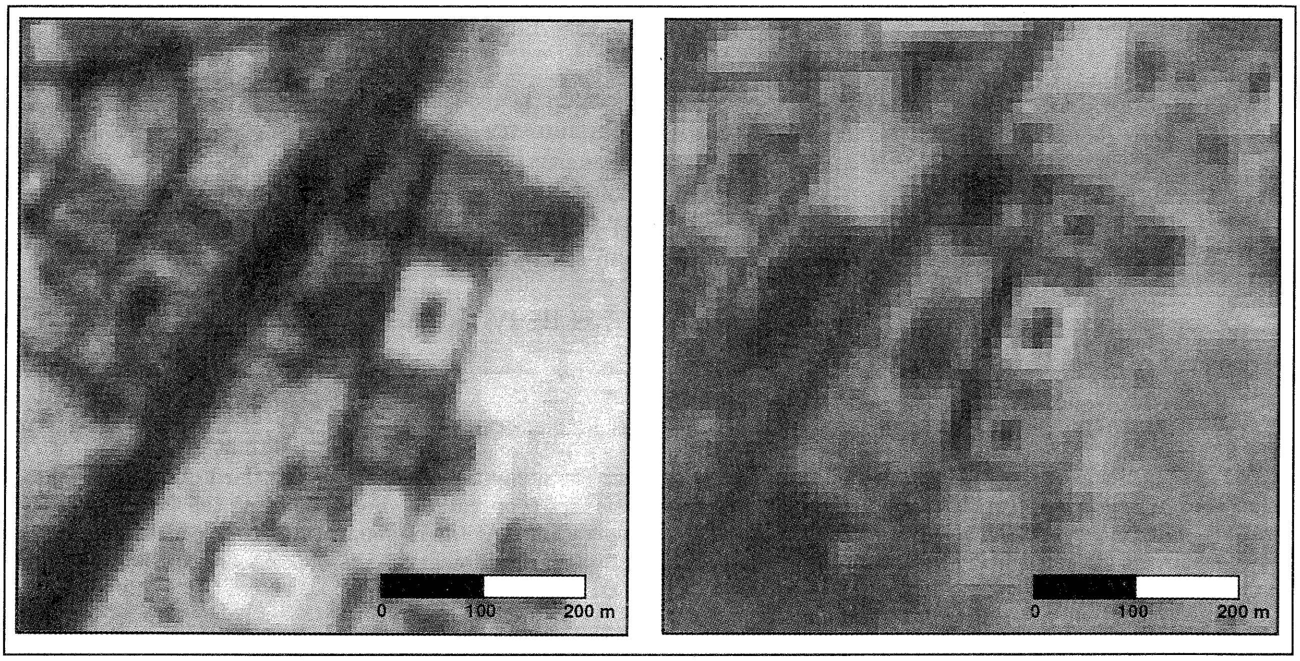

Figure 3: Comparsion of the information content between MOMS-02/D2 (left) and SPOT-HRV (right), test site Dubai

5 CONCLUSIONS

The theoretical as well as the practical examinations of the cartographical potential have shown that MOMS-02 data can be used for a fast and relatively cheap creation and revision of topographical databases at medium scales in the order of 1 : 50 000 or 1 : 25 000. Compared to sensors like SPOT or the proposed 1-m-U.S.-systems MOMS-02 offers a good compromise regarding the pixel size and the swath width which is optimized for scales around 1 : 25 000. Depending on the specific application the quality standards for the geometrical accuracy - especially for the vertical component - and for the catalogue of objects to be extracted have eventually to be lowered.

Furthermore, it has been shown that the method development, which is strongly embedded into the environment of a Geographical Information System (GIS), is able to satisfy the demand for an interactive and semi-automatic production of orthoimage or line maps (Schiewe, 1995).

So far, MOMS-02 was only of experimental nature. Better operational parameters compared to the MOMS-02/D2 mission are planned for the pre-operational MOMS-02/P mission onboard the Russian MIR-station from 1996 on as well as for the use as MOMS-03-freeflyer.

6 ACKNOWLEDGEMENTS

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