D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

EXPERIENCES FROM THE MOMS-02-PROJECT FOR FUTURE DEVELOPMENTS

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Key Words:
MOMS-02, mapping, sensor development, multi-resolution.

ABSTRACT:
The experiment with the German space-borne sensor MOMS-02 during the D2-Spacelab mission in 1993 revealed successful results concerning the topographical potential of the data in terms of their geometrical accuracies and their information content. From these experiences as well as from application demands recommendations for the sensor development in general and for a German contribution beyond this experiment will be presented.

1 INTRODUCTION

The development of space-borne sensors for earth observation purposes is driven by a bundle of non-separable factors, namely by

• technology (e.g., increasing sizes of CCD-sensors or data transfer rates),

• applications (e.g., the demand for up-to-date topographical maps and height data – see also section 3.2, or the existence of a variety of niche markets with different needs) and

• politics (e.g., the relaxation of military restrictions concerning spatial resolutions).

From a technical point of view this leads firstly to a trend towards *better resolutions* - not only in terms of geometry and radiometry, but also of time and spectral range - and secondly to a more flexible or *multi-resolution* use of the sensors. Hence, the functionality gap between space-borne sensors and the traditional photogrammetric cameras will be closed more and more.

On the other hand at present only a couple of sensors like the American Landsat TM, the French SPOT or the Indian IRS-1C/D are working operationally in orbit. But a couple of national agencies and private companies are planning to step into this market which is expected to grow significantly (Aplin et.al., 1997; Fritz, 1998).

Also Germany is operating on a long-term national programme since 20 years which culminated to the successful experimental use of the Modular Opto-electronic Multispectral Scanner in its second version during the D2-Spacelab-mission in 1993 (MOMS-02/D2). The key features of the system are described in chapter 2.

In the meantime the scientific data evaluation of the experimental D2-mission has been concluded. Special emphasis was laid on examinations regarding the topographic potential in order to overcome the world-wide deficits in mapping and revising medium-scale topographical databases by using conventional as well as automated methods. The promising results concerning the geometrical accuracies and the inherent information content will be summarized in chapter 3.

Since 1996 the MOMS-02 system is employed on-board the Priroda module of the Russian MIR station for a pre-operational mission (MOMS-02/P). Due to the well-known operational problems of the space station and to the fact that also the duration of this mission is limited, an outlook becomes necessary. Considering general trends mainly from the application side as well as the promising results of the D2-mission, a couple of recommendations will be presented in chapter 4 for the future development of earth observation sensors in general and for a German contribution in particular.

2 MOMS-02-SYSTEM

2.1 Operational features

During the 10 days lasting D2-mission the MOMS-02 camera system (figure 1) recorded about 7 million km^2 of the earth from an altitude of 300 km. Due to limited energy resources of the Space Shuttle carrier one could obtain test areas only within a belt of ± 28.5° latitude.

The identical instrument flies with the Priroda mission. Only the flying height (400 km) and the inclination (± 51.6°) have changed. Due to the mentioned operational problems this mission has produced only a comparable small number of images so far.

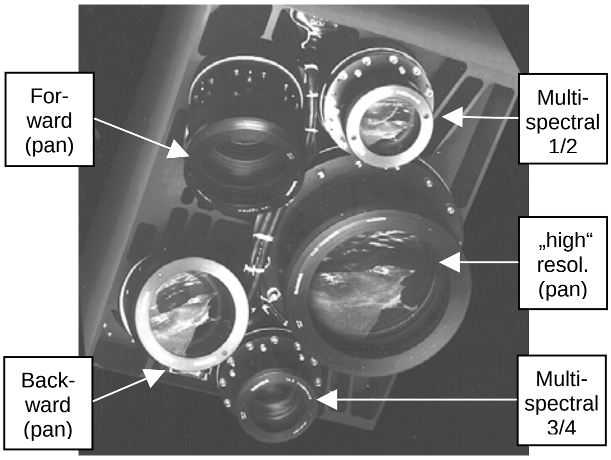

Figure 1: Optical module of MOMS-02 (© DLR)

It has to pointed out again that especially the first mission was only of experimental nature. One has to consider that the space segment was part of an entire space station so that the use of the sensor was rather limited. The project could simulate only a portion of an entire *remote sensing system* which is not only concerned with the image capture itself but also with producing value-added products or with marketing aspects. In the case of MOMS-02 ground segment tasks are mainly performed by a scientific team and marketing is done by the German Aerospace Center (DLR, 1998) rather than by commercial institutions.

2.2 Technical features

The key features of the MOMS-02 system can be expressed in terms of the various resolutions as well as the stereoscopic properties as follows:

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Sensor		QuickBird	IRS-1C/D	MOMS-02/D2	MOMS-02/P	SPOT	Landsat TM
Spatial resolution	pan	0.8 m	5.8 m	4.5 m	6.0 m	10.0 m	-
	MS	3.0 m	23.5 m	13.5 m	18.0 m	20.0 m	30.0 m
Spectral resolution (no. of channels)	pan	1	1	3		1	0
	vis	3	2	1		2	3
	IR	1	1	1		1	4
Temporal resolution		20 days	24 days	-		26 days	16 days
Radiometric resolution		11 bit	6...7 bit	8 bit		8bit	8 bit
Swath width		22 km	70 (141) km	27...78 km	36...105 km	60 (117) km	185 km
Stereo principle		along-track	across-track	along-track		across-track	across-track
Costs per km^2 (in USD)		?	0.14...0.57	0.06	0.13...0.94	0.61...1.19	0.06...0.12

Table 1: Comparison of technical features of operational and announced earth observation sensors (Schiewe, 1997a)

The **spatial resolution** can be described by the ground pixel size of 4.5 m for one (so-called "high-resolution") pan-chromatic channel and 13.5 m for all other channels. Due to the increased flying altitude with the Priroda mission these measures have been increased to 6 m resp. 18 m. Compared to the spatial resolution of other current operational sensors (e.g., SPOT: 10 m resp. 20 m; IRS-1C/D: 5.8 m resp. 23 m) these values are at the high end.

The **spectral resolution** is determined by three pan-chromatic channels (with a wavelength ranging from 520 to 760 nm) and four multi-spectral bands in the visible (blue, green, red) and near-infrared range. The latter four bands have been incorporated into two lenses (MS1/2, MS3/4; see figure 1). In contrast to the mentioned operational sensors the band widths of the multi-spectral channels are rather narrow (between 35 and 65 nm with MOMS-02 compared to 70 to 100 nm with SPOT) which indeed allows only a smaller amount of electro-magnetic energy to hit the sensor, but also enables a better spectral discrimination and hence better classification results (Berger and Kaufmann, 1995).

Due to limited data transfer and recording rates not all bands can be used simultaneously so that an a-priori selection according to the specific user needs has to be performed which leads to 7 different band combinations (resp. 4 modes during the Priroda mission). Depending on the selected mode the **swath width** varies between 37 km to 78 km (D2) resp. 36 km to 105 km (Priroda).

Like most of the other systems (SPOT, Landsat TM) MOMS-02 uses a **radiometric resolution** of 8 bit. In order to react more flexible upon atmospheric and ground conditions the actual 8 bit can be shifted within a frame of 12 bit by means of gain factors which have to be determined by the ground station a couple of hours before image acquisition.

Due to the already mentioned operational restrictions the **temporal resolution** of both MOMS-02 missions is unpredictable. Furthermore, MOMS-02 does not offer a side looking capability like SPOT. Hence, the possibility for a flexible data capture is rather limited.

Finally, MOMS-02 has offered as the first space-borne system an **along-track stereoscopic capability** which in contrast to the across-track principle (e.g., with SPOT) yields a more spectrally unique stereoscopic effect because the images belonging together are captured within a time period of 20 or 40 seconds instead of hours or days when the neighbouring orbit is reached. This leads to more reliable three-dimensional evaluations. The along-track principle is achieved through the use of lenses looking under a different viewing angle to the ground: Two about 21.4° forward resp. backward tilted lenses (also called "k6" resp. "k7") and one nadir-looking channel ("k5") allow for a two- or threefold stereoscopy (figure 2).

Summarizing these features one can state that MOMS-02 considers very much the above mentioned trends towards better and multi-resolutions. As table 1 indicates, it offers some features which are unique in the civilian field at present. Nevertheless, the announced future systems like QuickBird, SpaceImaging or Orb-View-3 will show even more improved technical parameters.

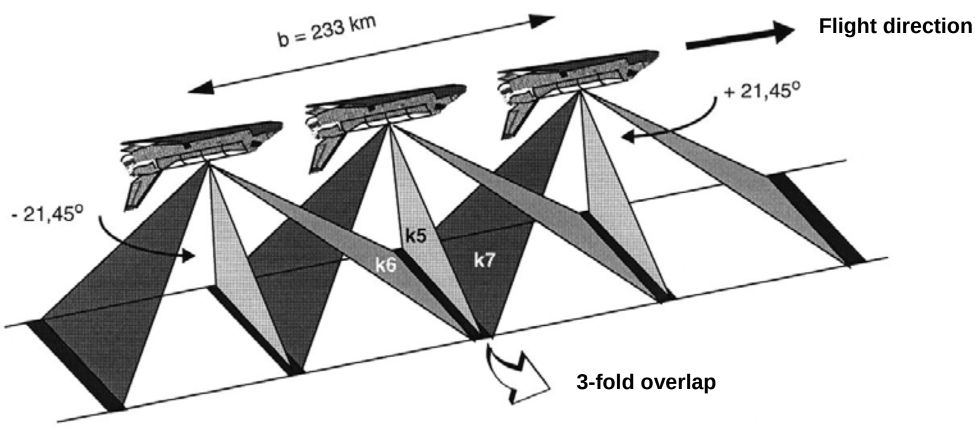

Figure 2: Along-track stereo principle of MOMS-02

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3 TECHNICAL EXPERIENCES

3.1 Overview of experiments

The MOMS-02 data evaluation and specific method development is performed by a science team consisting of numerous institutes from German universities and by the German Aerospace Center (DLR). Within the photogrammetric group of the science team a vertical task distribution was pursued:

• Determination of the interior and exterior orientation by the Technical University of Munich (Ebner et. al, 1996);

• Automatic extraction and matching of tie points as well as the generation of Digital Elevation Models by the University of Stuttgart (Fritsch, 1996);

• Digital stereo measurement and topographical evaluations by the University of Hannover;

• Analytical evaluations after a D/A-image conversion by the University of the Armed Forces, Munich (Dorrer et.al., 1995).

In the following this paper will emphasize on the own work on topographic evaluations. Nevertheless, the necessity of the previous work of the partners should not be denied. The integrated work of the science team has been proved successful although the described sequential task distribution was not always efficient (e.g., due to the necessity of working with different test sites) and was consequently given up in some parts.

Figure 3: Part of test site Dubai-City
(approx. 2 • 1.5 km^2, © DLR)

3.2 Topographical potential

One major – if not the most important - goal of the MOMS-02 mission was to contribute to the problem of creating and updating medium-scale topographic databases in analogue or digital form. Not only the small absolute numbers (e.g., 66.5% of the world is not mapped at a scale of 1 : 25 000), but also the low progress (e.g., annual rates of 2.8% for the creation or 4.9% for the revision, each at a scale of 1 : 25 000) can not satisfy the user demands (Konecny and Schiewe, 1996).

These numbers were the motivation to examine the suitability of MOMS-02 as being a space-borne electro-optical sensor with appropriate resolutions and coverage for medium-scale mapping purposes. Hence, in a first stage of the examinations the goal was to check if MOMS-02 image data are able to meet the geometrical (section 3.2.1) and semantical standards (section 3.2.2).

Because the commercially available software tools were not able to handle line scanner imagery in general and MOMS-02 in particular – which is still the status at present - a specific processing chain had to be developed for these tasks. The resulting software modules are currently integrated into a Digital Photogrammetric System (Schiewe, 1997a).

The following results are based upon data from the test sites Dubai-City (United Arab Emirates; figure 3) and Harare (Zimbabwe). Due to the limited operational features (see section 2.1) it was not possible to cover regions in developed countries during the D2-mission.

3.2.1 Geometrical potential. Goal of the geometrical tests was to assess the accuracy of discrete object points and to discuss from these measures the suitability for certain scales or applications.

In order to obtain the residuals of Independent Control Points (ICPs) as an accuracy measure the image orientations had to be determined. While the **interior orientation** resulted from a pre- and a post-flight calibration of the camera, the **exterior orientation** had still to be determined using Ground Control Points (GCPs) because no appropriate orbit data (GPS, INS) could be recorded during the D2-mission.

The preceding operations for the determination of the exterior orientation are starting with the manual **image coordinate measurement** for GCPs and ICPs by on-screen-digitizing. The following rules have to obeyed in order to end up with the best results as possible:

• The number of GCPs (with a minimum of three which is necessary for the following bundle adjustment) is of minor importance, whereas the quality of the points in terms of a good contrast both in topography and in the image effect the results significantly. Also the structure of the targets itself (preferably narrow road crossings) is of major importance.

• In the case of visual stereoscopic measurements it could be shown that the imagery acquired in the along-track mode facilitates an improvement within the resulting height accuracy about factor 2 compared to monoscopic measurements.

• The optimal combination of stereo channels consists of the nadir looking “high-resolution” channel (4.5 m) and one of the oblique looking channels of minor spatial resolution (13.5 m) which has to be enlarged by factor three. Although the base-to-height-ratio is decreased, one yields much better pointing accuracies (in the order of 0.3 pixel) through the use of the 4.5-m-channel compared with the standard solution using the forward and the backward looking band.

• Applying automatic measurements the relative accuracies are increasing to 0.1 to 0.2 pixel. Here the use of both oblique looking channels of the same spatial resolution should be preferred because the automatic image matching algorithms can not adjust for the difference in resolutions as good as the human eye is able to do.

Due to the lack of more accurate **reference coordinates** these have been digitized from orthoimage or topographical maps at a scale of 1 : 10 000 and smaller.

The interior orientation as well as the image and reference coordinates are the input for the following **bundle adjustment** which

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had to be developed particularly for line scanner imagery like that from MOMS-02. The applied method assumes a standard Kepler ellipse as a default orbit and models disturbances coming from variations of the read-out frequencies and from an angle between orbit and scan line through additional parameters. With that, the adjustment proved to be accurate enough for short orbits of 100 to 200 km.

Applying the described methodology one ends up with the desired **geometrical accuracies** of the ICPs which amount to

3 m to 5 m in position and
5 m to 7 m in height

under optimal conditions. These accuracies correspond to the theoretical expectations that are able to meet the demands for topographical maps at a scale of 1 : 25 000 (at least in position). Nevertheless, for a concrete application the absolute accuracy values rather than the scale number have to be considered.

3.2.2 Semantical potential. Goal of the semantical examinations is the assessment of the detectability and interpretability of particular objects or object groups.

Because general automatic image interpretation procedures are far away from being operational and specific methods for MOMS-02 imagery are still under development (see section 4.1), the evaluation will be based upon visual comparisons with reference maps or with data of other sensors. Due to the fact that only two reasonable test areas could be examined, quantitative measures (e.g., percentages of detected objects) would not be of statistical significance, so that the following results will be expressed only qualitatively.

Considering the **road network** it can be stated that objects with a width down to 3 m to 5 m can be extracted nearly completely from MOMS-02 data.

As expected the derivation of **buildings** especially in an urban environment is rather limited. Even if the object size itself exceeds 2 to 3 pixels in both directions (i.e., approx. 9 m to 15 m) the distance and therefore the contrast between the objects is too small resp. too low.

Nevertheless, compared to SPOT data there is a clear progress for the detectabilty rate so that MOMS-02 could be a compromise between SPOT and aerial imagery for certain applications (figure 3).

Regarding **vegetation** areas it can be stated that major classes as displayed in topographical maps at scales of 1 : 25 000 to 1 : 50 000 can be detected. Here, MOMS-02 yields considerable advantages through the acquisition of multi-spectral and multi-spatial resolution data which can be fused later (see also section 4.1).

The success rate for detecting regional and linear **water** features can be compared to that of road networks. Even if the linear structures are not as smooth as roads the use of multi-spectral data (especially in the near IR band) yields a significant distinction from all other objects.

Summarizing these results it can be concluded that the information content of MOMS-02 imagery is capable to fulfill the demands of most medium-scale applications. But like with the geometrical accuracies the obtained results have to be carefully compared with the specific application.

4 FUTURE DEVELOPMENTS

As already pointed out the development of space borne sensors for earth observation is embedded into a tension field of politics, technology and applications (figure 5).

While in the past the direction of development was driven in this sequence, the relaxation of military constraints as well as the enormous technical development allow for a strategy starting with application aspects.

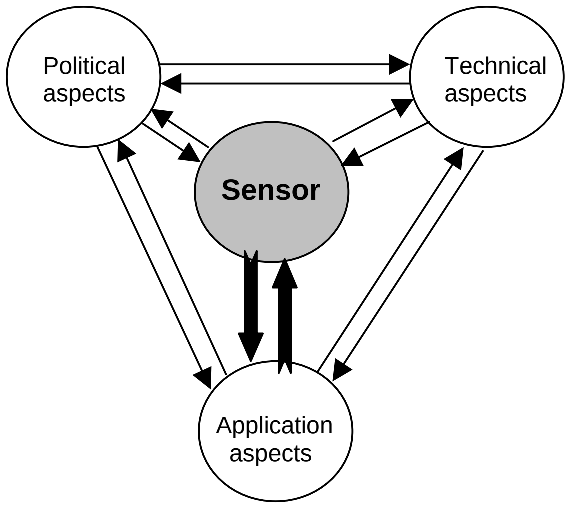

Figure 5: Tension field for sensor development

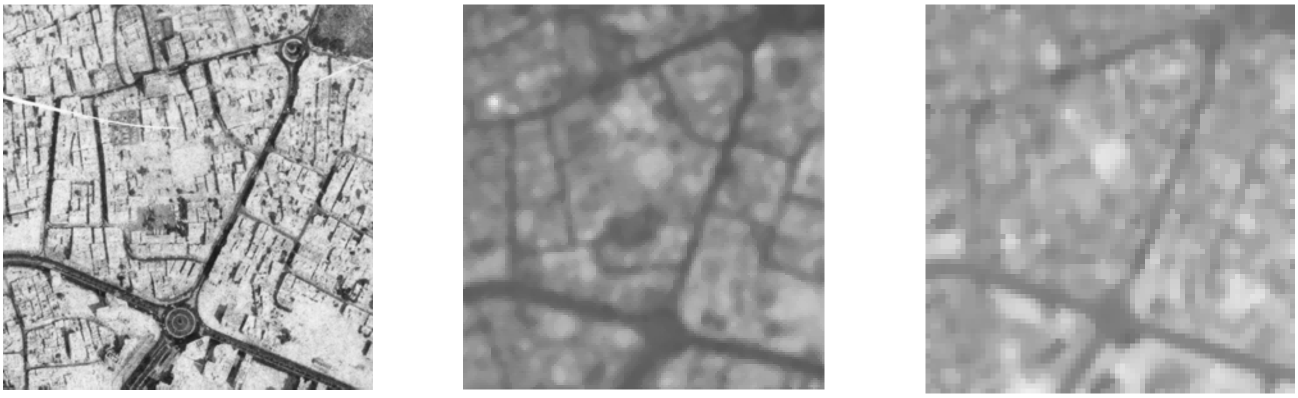

Figure 4: Comparison between aerial image, MOMS-02 and SPOT for interpretation purposes
(test site Dubai-City, size approx. 700 • 700 m^2, © DLR)

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4.1 Application aspects

Looking in particular on the further development of the MOMS-programme which - as discussed in the previous chapter - has been proved very successful, a couple of problems have to be dealt with. Some of these which have also be addressed practically in the project work will be pointed out in the following.

• Problem: Sensor classification
Due to the announced commercial US-Systems like QuickBird, SpaceImaging or OrbView-3 it becomes more and more obvious that there is a strong need for a standardization of earth observation sensors. In order to give the users reasonable comparison possibilities a fixed scheme has to be elaborated rather than the current practise that the vendors are calling their system just “high resolution” (like for MOMS-02).

One possibility is the recommendation of Fritz (1998) who claims five classes on the base of spatial resolutions with break points at 0.5 m, 3 m, 30 m and 300 m. A more general recommendation could come up with systems with resolutions in the “high” (< 2m), “medium“ and “low“ (>75 m) range. This scheme considers the empirical limits for interpreting certain features (e.g., roads can be generally detected only in “high” resolution imagery) and corresponds to the accuracy standards of large, medium and small vector map scales (with the standardized break points at the scales 1 : 10 000 and 1 : 300 000 as well as accuracy values of 0.2 mm at map scale for the vector domain resp. 0.8 times the pixel size for the digital image domain).

• Problem: Need for medium resolution systems
Also because of the announced American system the questions arises whether future developments of systems in the “medium” resolution range (as just defined) – like MOMS-02 - will be necessary. A lot of practical arguments affirm the necessity:

Due to technical limitations there is still a linear relation between spatial resolution and swath width (figure 6). Using “high” resolution systems the number of scenes would have to be increased quadratically for a certain application which causes additional time and costs for buying, storing and processing the data.

Furthermore, an increase in spatial resolution means in general a decrease in spectral resolution due to technical limitations (Aplin et.al., 1997), but causes also an increase in within-field spectral variations which is very often a problem for classifications.

Finally, there is certainly not a “perfect” sensor in the “medium” range. In contrast to other sensors (like SPOT or IRS-1C/D) MOMS-02 offers advantages concerning the along-track stereo capability and the narrow spectral band design. On the other hand it shows disadvantages regarding flexible imaging conditions (e.g., through the possibility of across pointing).

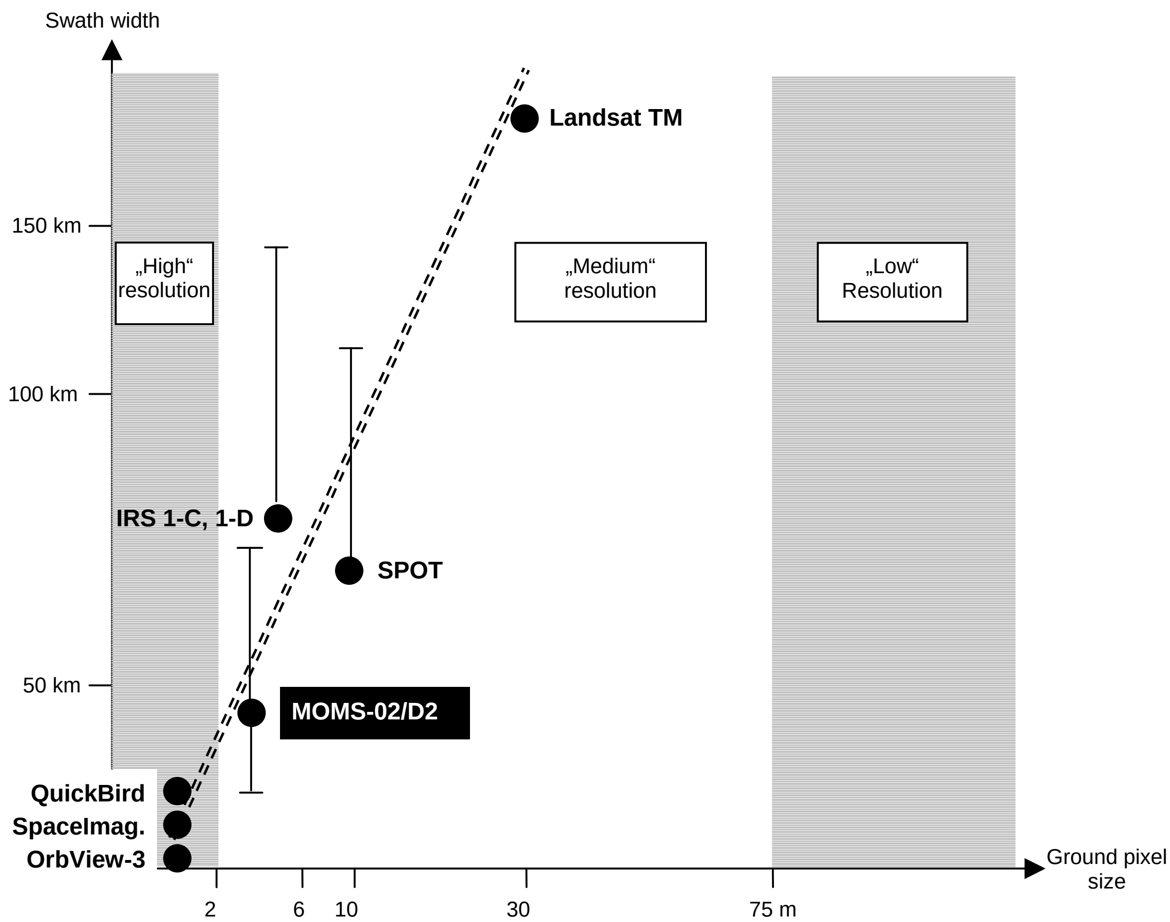

Figure 6: Connection between spatial resolution and swath width of space-borne sensors

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• **Problem: Processing multi-resolution imagery**
It is generally known that no single sensor is able to tackle the various and continuously growing demands of the user community. Hence, the use of multi-resolution data (with respect to spatial, spectral, radiometric, and temporal resolutions) is necessary. On the other hand two problems arise from this demand:

Firstly, the handling of huge amounts of data leads automatically to the task of *image compression*. Within our project we dealt with lossy compression techniques in order to obtain compression rates of 10 and higher. The examinations considered not only the effect of these algorithms on further manual or automatic procedures, but also the impact on the geometrical as well as the semantical potential of the MOMS-02 data.

Summarizing the results (Schiewe, 1997a) it can be concluded that a new Wavelet-method is superior against the well known JPEG algorithm. Furthermore, one has to differentiate between following manual evaluations (with acceptable rates in the order of 15 to 30) and automatic operations where significant losses occur at very low rates due to the fact that important structures with high frequencies are eliminated through the compression.

The second problem which arises is the fact that data fusion methods have not become operational so far. Within this project we applied various pixel-based methods with the goal to obtain a better discrimination of vegetation classes. It can be pointed out that merging the pan-chromatic channel (4.5 m spatial resolution) with the multi-spectral bands (13.5 m) using standard IHS- or Brovey-transformations lead to a significant improvement for the visual interpretation task. Nevertheless, more advanced and probably more effective methods (like feature- or decision-based methods; Pohl and van Genderen, 1998) have not been taken into account so far.

• **Problem: Missing automatic interpretation methods**
The absence of operational and reliable automatic interpretation methods lead to the fact that the digital data chain from acquisition over processing to output shows a major breach which leads to the fact that the use of digital data is very often not accepted.

This problem has also been addressed in a variety of subprojects within the MOMS-02 science team whereby the methodology and efficiency of specific automatic revision methods using MOMS-02 imagery for certain object types have been examined. At the University of Hannover, an approach using the existing database in combination with image pre-processing and topological post-processing steps yielded promising results for the update of water areas (Schiewe, 1997b). The values of 6.0% omission errors (i.e., actual water not detected) and 8.3% commission errors (i.e., water classified although there is no water) are very much comparable to those of an interactive process.

• **Problem: Data offering**
Concerning the commercial part not only a comparable low price but also an advanced user-oriented data offering via the Internet (including value-added data and meta data) is becoming more and more important as potential users pointed out several times.

Summarizing these application aspects it is obvious that the future use and therefore the future development of earth observing sensors will rely very much on the progress of algorithmic problems like interpretation, fusion or compression of multi-resolution data.

4.2 Technical aspects

Considering the application aspects as well as the technical development a couple of recommendations for the design of a future “medium” resolution sensor can be given. From our experiences the key values according to the technical features as pointed out in section 2.2 are as follows:

• A future system must have significantly larger **swath widths** than the announced American high resolution systems (100 km or larger).

• A **spatial resolution** resp. a pixel size of 5 m seems to be sufficient if one tolerates that not all object types (like single buildings) can be mapped as it could be seen with MOMS-02 data.

• The **temporal resolution** shall be at least that of SPOT or IRS-1C/D (including a sideward-looking possibility).

• The **spectral resolution** in terms of the band widths should be developed towards the features of the MOMS-02 system. Additional bands in the near and mid IR range would provide an improvement for classification tasks.

• An **along-track stereo** capability is mandatory. Because the data transfer and recording rates are still a limiting factor a solution of using only two channels with a resolution as good as possible should be preferred rather than three channels with different resolutions (like in the case of MOMS-02).

• The **radiometric resolution** should be at least 8 bit. If image processing systems will developed further a value of 11 or 12 bit can be taken into consideration.

Summarizing these aspects the development of a future system in the “medium” resolution range should place the emphasis on multi-resolution properties rather than on better resolutions. Anyhow, the costs per km^2 have to be kept significantly lower than those of “high” resolution sensors.

5 SUMMARY AND CONCLUSIONS

The German MOMS-02 experiment has fulfilled the expectations from a technical point of view. The geometrical accuracies and the inherent information content of the imagery is able to tackle most of the mapping tasks in medium-scale range down to a scale of 1 : 25 000.

The future development of earth observing sensors is influenced by the non-separable aspects of applications, technology and politics.

Concerning the **application aspects** firstly a standardization of sensors should be striven for. In this context, a recommendation for a rough classification in three groups (“high”, “medium” and “low” resolution) with break points at 2 m resp. 75 m pixel size was given. It can be expected that the design of a new space-borne sensor in the “medium” resolution range is a necessary and soluble task.

The future use of earth observing sensor data and therefore the future development of sensors will rely very much on the progress of algorithmic problems like automatic interpretation, data fusion or data compression.

From that a couple of recommendations concerning the potential **technical design** of a space-borne sensor could be given. It can be expected that the data transfer and on-board-storage limitations will have no importance in the near future so that the trend to a flexible, multi-resolution system (in terms of all resolutions!) can be pursued very soon.

Considering finally the **political dimension** it can be concluded that a system that enables global coverage is an international task and therefore needs an international organisation. In this context a future German contribution, which goes beyond the successful pilot project MOMS-02, should be integrated into an international co-operation.

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6 ACKNOWLEDGEMENTS

The presented results are part of a research project which has been funded by the German Aerospace Center (DLR, formerly DARA) and have been conducted at the University of Hannover (Institute for Photogrammetry and Engineering Surveys).

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