The Bright Future of High Resolution Satellite Remote Sensing – Will Aerial Photogrammetry Become Obsolete?

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ABSTRACT

High resolution satellite systems today become more and more important. The reason is simple as the technology developments of the last ten years changed the situation dramatically. Satellite Constellations for observation with a very high spatial and radiometric resolution are now state of the art technology. Even systems with a spatial resolution of 50 cm are available with a brilliant image contrast and an extreme good signal to noise ratio. In terms of flexibility the high agility of such systems is one of the important parameters. Beyond the instrument and satellite technology, the importance of automatic data processing has increased. Deriving high resolution 3D models is one of the most challenging topics. To optimise such complex systems for certain tasks, the complete system chain has to be considered. This paper shows the status of the work and gives an outlook for the next generation of high-resolution optical satellite technology.

1. INTRODUCTION

The basic research for all technologies needed for high resolution Earth observation systems is completed. In addition, the proof-of-concept inputs and the pioneer work of our colleges in USA demonstrate the operability. As part of a DLR & EADS-Astrium team we are working together on a system of high resolution optical satellites which will be able to provide input data for 3D virtual reality GIS data base. The generation of 3D models based on imagery acquired by spaceborne systems has been a well-known process for more than two decades. Within the last couple of years, there were a number of revolutionary changes – a higher geometrical resolution reaching a ground sampling distance better than 1 m, a very high agility allowing along-track stereo capability and powerful stereo matching algorithms. These algorithms are extremely important regarding the End-to-End system capability for optimization purposes. Due to the basic algorithms developed for airborne applications, we and our partners at Digital Globe are able to investigate the influence of different along-track stereo angles in terms of the total accuracy of the 3D data product.

Another reason for the growing importance of high-resolution satellite systems are system parameters like accuracy of geo-location, which has to be better than 4 m without ground-control points. This figure drives the line-of-sight requirement of the space segment. After post-processing applying ground control points, the absolute accuracy can be better than ground sampling distance.

2. HIGH RESOLUTION OPTICAL INSTRUMENTS

In terms of the optical instrument accuracy and the system parameters a fixed alignment between the primary mirror and the star camera with internal IMU is required. This star camera technology allows that the drift-compensated orientation data can be contained in the house keeping part of the image data. This telescope design as an example for a high resolution telescope was developed by EADS Astrium GmbH. The figure below shows the telescope at the environmental test level.

In order to fulfill the SNR requirement using a telescope with an F-number of 11.5 TDI technology is required for the detector. This approach is based on the basic idea of forward motion compensation applied at airborne cameras.

The technical parameters of the telescope are:

Focal length:	8.75 m
Aperture:	75 cm
F-number:	11.5
Wave length:	450 nm … 900 nm
MTF (@ 57 lp/mm):	> 24 %

Fig. 1: The telescope at the environmental test.

In addition the timing scheme of the detector will be controlled so that the motion blur in flight direction is minimized. Figure 2 shows the DLR focal plane design of a TDI sensor head designed.

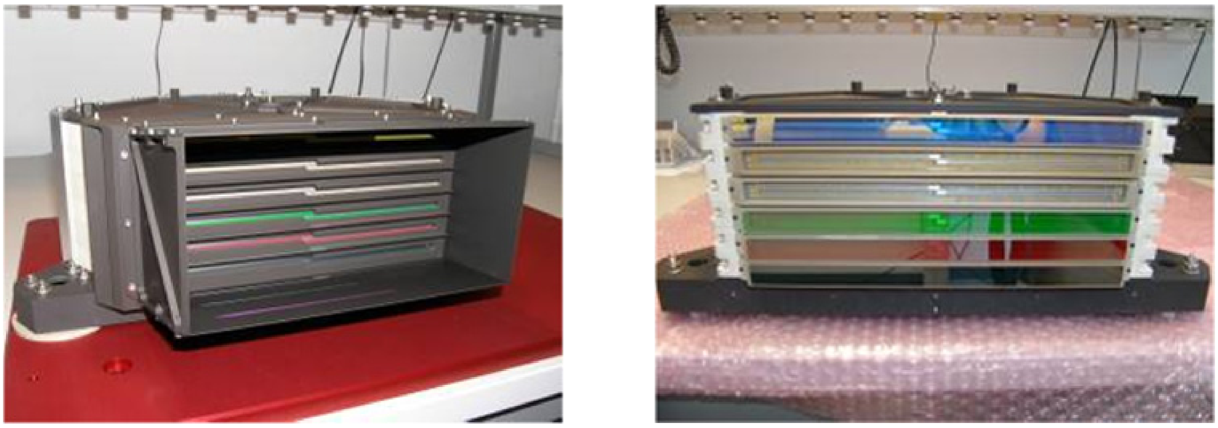

Fig. 2: Modular focal plane stack.

The focal plane deployed for a spaceborne payload contains two panchromatic CCD lines (PAN) and four multispectral (MS) CCD lines. The key parameters of the sensor head are:

PAN-Pitch:	8.75 µm
MS-Pitch:	17.5 µm
PAN-TDI-Steps:	1/ 8/ 32/ 64
MS-TDI-Steps:	1/ 8/ 32/ 64
PAN Nr. Pixel:	24,000
MS Nr. Pixel:	12,000
PAN full well capacity:	470 ke^-
MS full well capacity:	1,000 ke^-
Dynamics:	14 Bit
Total rms noise:	6 LSB
PAN Line rate:	500 … 14,500 Hz free programmable
MS Line rate:	500 … 7,250 Hz free programmable
PAN MTF:	52 % Solar weighted at Nyquist

Overall system MTF will be better than 12 %. An SNR better than 200 is estimated under the constraints of an albedo of 20 % and a view and sun zenith angle of 20°.

3. NEW GEO-LOCATION FEATURES OF SATELLITE BUS

Why is geo-location without ground-control points so important? The answer is directly connected to the processing time. Inside the ground-segment development the image processing has to be minimized. For that purpose a better geo-location allows the application of simpler algorithms to register satellite imagery coming from geo data base or from radar satellites into the ground-control point network.

In order to fulfill this requirement a typical approach from airborne line cameras is used. To obtain the position at the orbit, a high precise dual-band GPS receiver with an accuracy of better than 10 cm is integrated in the spacecraft bus. To measure the orientation in space, star cameras with an accuracy better than 1 arcsec with integrated IMU's of the same accuracy are mounted directly on the M1 mirror. The star cameras are able to deliver the orientation in 10 Hz and will compensate the drift of the IMU which will give us the orientation data in 200 Hz. The star-camera system frequency is now 200 Hz. A statistic prediction algorithm generates the orientation of the image data between the 200 Hz and 14 kHz image data. In the ground segment the orientation and position data are processed in two ways (forward and backward), and as a result the geo-location of 4 m can be achieved.

4. 3D DATA PRODUCTS GENERATED FROM OPTICAL SATELLITE SYSTEMS

The processing flow for satellite imagery equals that one of aerial data and can be divided in three major steps – pre-processing, matching, and post-processing. Pre- and post-processing are not dependent on image content. These steps are now recognized procedures and have been in use for some time. The main task is image matching, depending on strong image content.

Pre-processing covers all steps necessary for image matching:
Formatting: Input data (images, interior and exterior orientation data) have to be converted into a specific format depending on defined interfaces. Time synchronization and the elimination of all systematic errors are assumed.
Masking: Since the matching algorithm cannot handle areas being covered by clouds or water these areas have to be masked manually or automatically.
Bundle adjustment: Using ground control and tie points a bundle adjustment has to be executed resulting in epipolar geometry. Although most of satellite sensor systems are line scanners this projection can be realized without any problem due to the very smooth flight path.

Image matching is the most challenging step within the processing chain. DLR applies a stereo matching algorithm as a standard relying on the Semi-Global Matching (SGM) method (Hirschmüller, 2008). This algorithm is based on minimizing a global cost function with a data and a smoothness term. The data term computes pixelwise matching costs using different approaches to compensate against a wide range of radiometric distortions. There are many global stereo algorithms that approximate this minimization, but they are typically slow. SGM is an efficient method for minimizing the global cost function. The implemented algorithm includes consistency check and failure elimination. Sub-pixel accuracy is achieved by applying quadratic interpolation. SGM works with image pairs. If more than two images are available, parallel matching and subsequent median filtering is executed in order to determine disparity values robustly from redundant measurements. Image matching results in disparity maps.

Post-processing contains production, filtering and texturing of an elevation model. Classical approaches are applied for producing a digital surface model (DSM) out of the disparity map. Digital terrain models (DTM) can be derived using several filter algorithms considering 2D and 3D knowledge, i.e. image texture and smoothness of the elevation model. Input image data can be projected on any elevation model being available (plane, DSM, DTM). True ortho photos based on DSM are a standard product. Figure 3a depicts level 1 data, true ortho image and DOM of 7cm GSD data of Ultracam X. Airborne systems are used as a kind of precursor systems for spaceborne missions.

Oblique projections can be realized including facade texturing from oblique views of the airborne data (Lehmann et al, 2009) (Figure 3b).

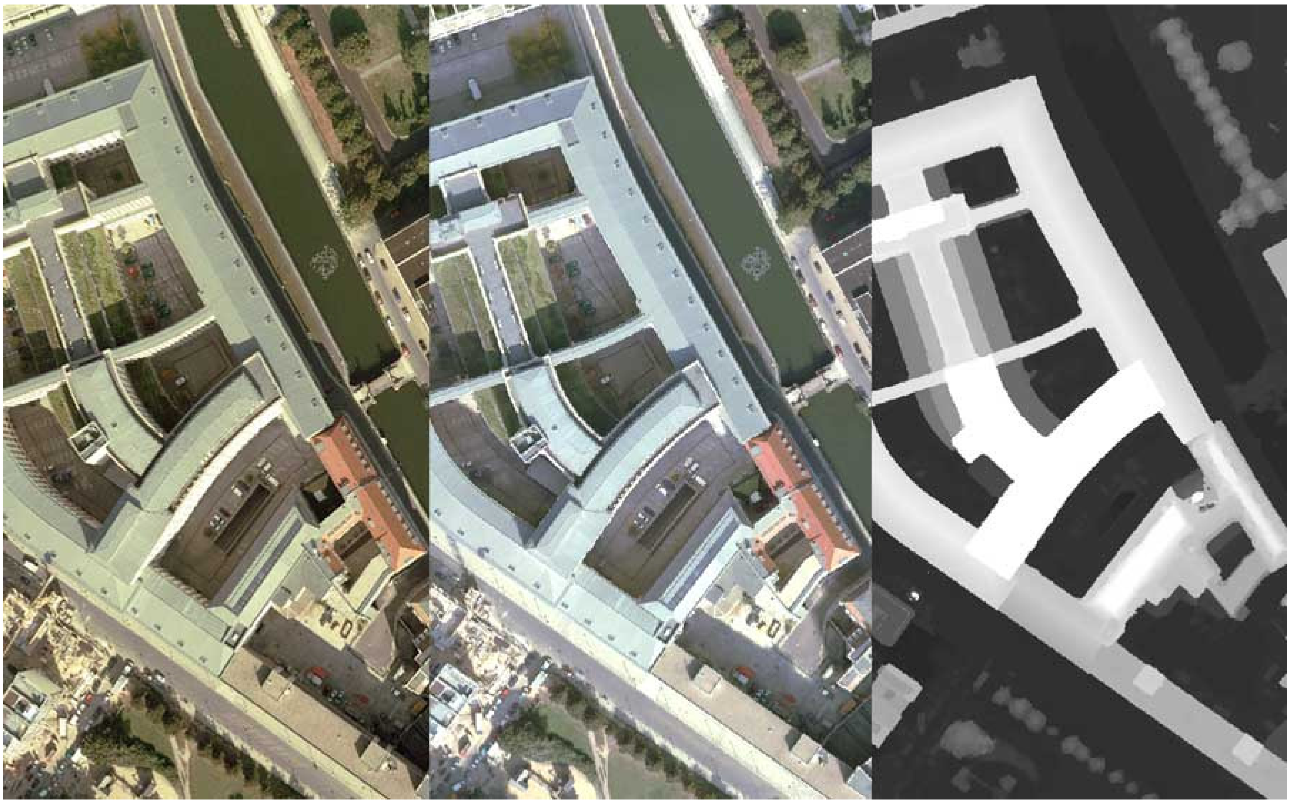

Fig. 3a: Level 1, True Ortho and DOM of 7cm GSD Ultracam X Data of Berlin.

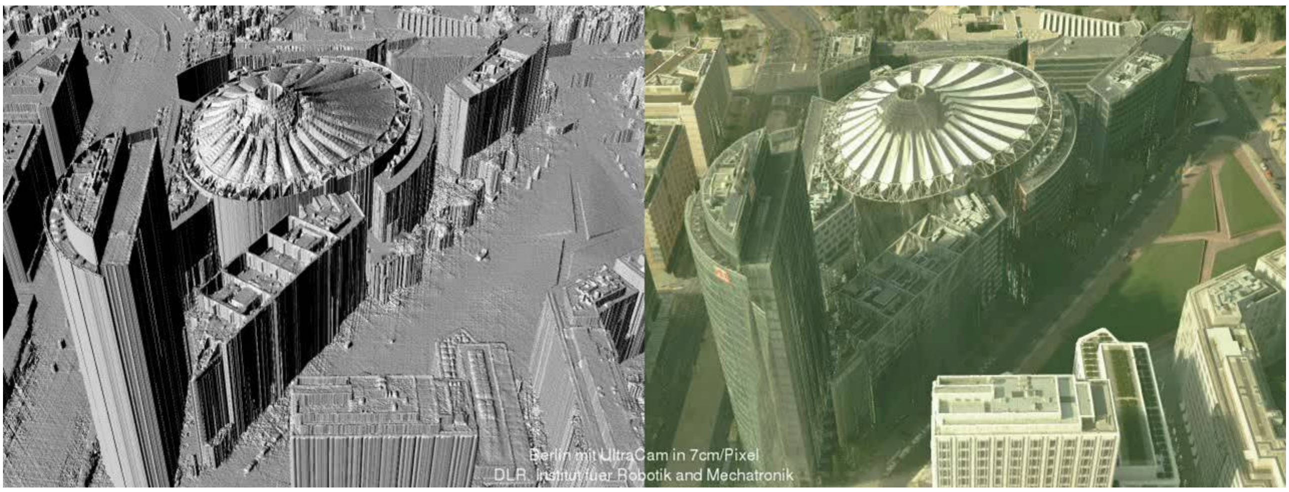

Fig. 3b: DOM and textured model of 7cm GSD Data of Berlin Sony Center.

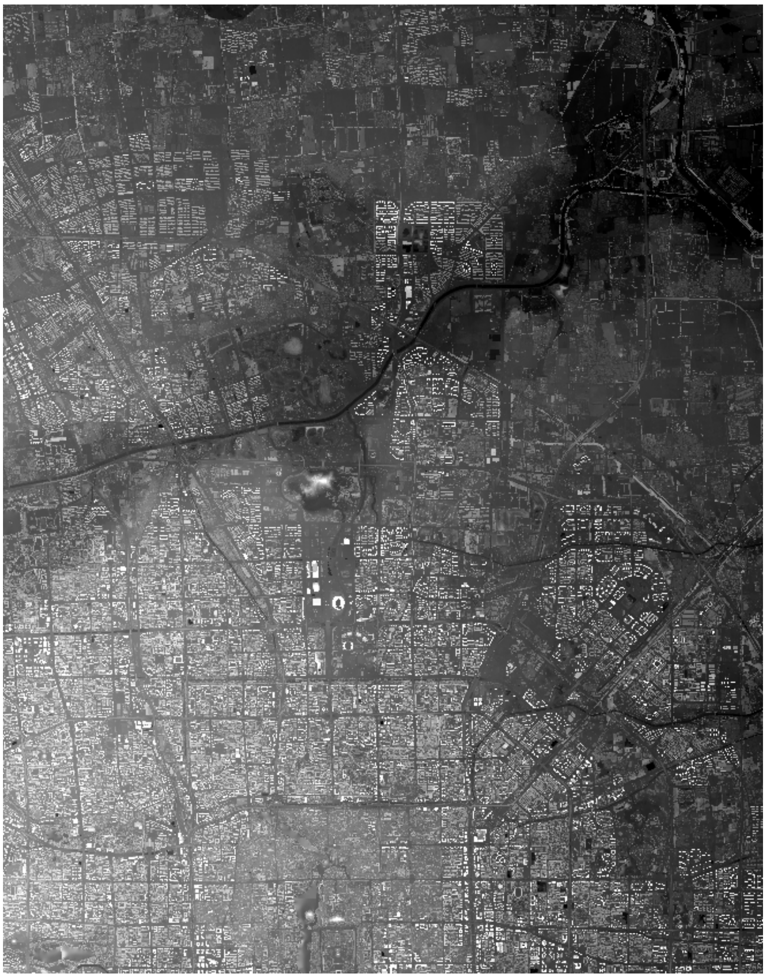

Fig. 4: Digital surface model of Beijing based on World View 1 data, overview.

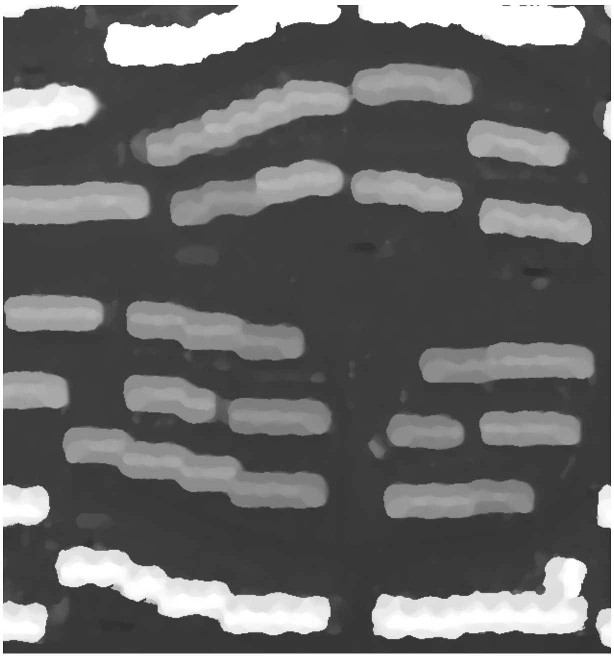

Fig. 5: Digital surface model of Beijing based on World View 1 data, detail.

Fig. 6: True ortho photo of Beijing data set corresponding to DSM, detail.

In 2008 DLR processed a World View 1 data set taken over Beijing (China). This data set was used to evaluate the complete processing chain regarding process flow, processing time and quality in order to estimate the efficiency of the approach, and to determine constraints and restrictions. Assuming a single CPU the complete processing of 1 km² of WV-1 data (ground sampling distance 55 cm) takes about one hour.

Figure 4 to 6 show products of the processing chain from DOMs to True Ortho Images, Figure 4 gives an example of a 3D visualization of DOM, True Ortho and facade texture information from oblique views.

Currently, DLR develops specific hardware configurations to expedite the process. Two different approaches are used – implementation on graphics processing units (GPU) (Ernst, Hirschmüller 2008) and on field programmable gate arrays (FPGA). Both concepts show very promising results already gained in the development phase.

5. MAPPING POTENTIAL VERSUS AERIAL CAMERA DATA

Using different satellite views of an area of approximately 400 square kilometers of the city area of Beijing a surprising quality of digital surface models (DOMs), true ortho images and 3D animations can be achieved. Relative position accuracy is around 50 cm giving a clear but limited structure sharpness of 3D objects in the scene. Mapping down to scales of 1:5000 seems reasonable as noted by other authors (Jacobsen, 2009). This is comparable to medium to high altitude digital aerial camera data (approx. 5000 m flight alt. e.g., depending on digital camera type). Scales of 1:500 to 1:2000 as often required in aerial city mapping cannot be achieved using the 50 cm resolution satellite technology. Due to the high cost factor and the problems regarding aircraft availability to cover large areas around the world, 50 cm satellite topographic mapping is a big step forward to accommodate lots of different applications and customer needs. An improvement of radiometric resolution in the shadow areas seems to be of much more importance now for data evaluation than 10 cm down to higher resolutions of 40 cm.

6. TECHNICAL DIFFICULTIES FOR HIGHER RESOLUTION AND NEXT STEPS

DLR is working on new technologies for the standard high resolution of 0.5 m GSD and on medium and very high resolution systems. The typical technical difficulty is the trade-off between numbers of TDI steps and aperture size of the telescope. As we know already from the technologies used in the Hubble Space Telescope (F-number 57.6 m) a 2.4 m (10 nm rms surface accuracy) mirror, two difficulties need to be resolved: the first is the extreme long manufacturing and production time and the second one is the research to overcome the structure environment stress during the launch phase. The main issue to be investigated is research on new mirror material based on the knowledge gained in the Hubble mission and taking into account the market needs.

In order to achieve a good image quality both the MTF and the SNR are very important. To achieve the best performances using the highest resolution and high agility it is necessary to introduce a dynamic focus mechanism control (DFMC) for the focal plane. This mechanism is only driven by the orientation of the satellite. In addition to the DFMC with high dynamic the secondary mirror has to be controlled with lower dynamic to compensate the entire setting problems of the mechanical structure at launch phase and the zero G problems in terms of the laboratory calibration equipment.
Nevertheless, scientists are working worldwide to solve these problems and to provide solutions with respect to all of these components, as well as to the down link rate from up to 4 GBit/s, via

optical communication. The same is true for the next generation of on-board data compression and mass-memory systems. The current down-link technology is focused on the dual polarized X-band downlink with a performance of 600 up to 800 MBit/s.

The flexibility and availability of the satellites will be also increased by the task control via two or more geo-stationary communication satellites. For that reason two different technological solutions have been developed. The conservative solution based on a Ka-band patch antenna which can be easily used for this application, but which has the difficulty of the reduced downlink capability. The new shining star of communication is based on the laser communication terminal which will be able to transfer in an order of 4 GBit/s also via the geostationary satellite. The difficulty here is that the terminal can be used only as unidirectional link. To solve this problem scientific groups are working on the combination between the Ka-band patch antennas for worldwide accessible tasking, and the optical communication link for data downlink.

7. CONCLUSION

The Hubble Space Telescope which has a telescope with 57.6 m focal length and the F-number of 24. It could be used for good weather earth observation and it might be able to realize a GSD of 7.5 cm from the 500 km orbit. To compare this to state of the art airborne camera systems which have typically an optics with F-number of 4 the sensitivity difference will be a factor of 36. In addition, the integration time which is related to the ground speed will be also very different. For the aircraft (350 km/h; GSD 7.5 cm) application the integration time will be in an order of 0.77 ms and for satellite (500 km orbit, GSD 7.5 cm) by ground speed of 7,047 m/s the integration time of 0.011 ms can be expected. The factor 70 between the space- and airborne systems is given. The total sensitivity differences will be a factor of 2,520. One of the typical solutions to overcome these problems is to enhance the detector sensitivity by the factor of 512 by the TDI technology. The additional factor of 5 between the space- and airborne solution can be solved by forward motion compensation. This very simple calculation shows that the performances of space- and airborne systems are comparable. If we look now to the latest development in the nanotechnology such as black silicon, the possibility to obtain the same image quality from the space system as from airborne system might be possible.

In the meantime and also for GSD down to 1 cm airborne and spaceborne system can be jointly used to fulfill all of the user requirements. However spaceborne systems will become more and more dominant due to the 10 % duty cycle of each 90 min orbit and life times of higher than 5 years. Such system includes the capability to generate approximately 45,000 square kilometers per orbit or better 720,000 square kilometers a day of one satellite. An airborne system needs more than 1,100 h imaging time (350 km/h, 7.5 cm GSD, 24,000 pixel like ADS) to cover the same area.
Another conclusion is that spaceborne systems also have an extremely high availability for large scale and large area mapping. In combination with airborne systems which can generate very high resolution images the systems can work to complement each other. If we look into the future, systems with 25 cm GSD spaceborne based will be implemented and that will drive the airborne mapping system in the highest resolution which can be achieved better than 1 cm GSD. Only then will the systems be really interesting for the market to fill the resolution gap. In terms of accessibility the spaceborne systems have a clear advantage, because within less than 24 h any required area of the world can be scanned and the data product delivered in less than 25 h. In the northern and southern hemispheres the delivery time can be minimize to 7 h after order. In some cases it could take longer to get the tower clearance for the aircraft to start mapping the required area.

All these technologies will be available in the next four to five years. That should give the R&D teams an incentive drive for the development of state of the art real high-resolution airborne cameras.

8. ACKNOWLEDGEMENTS

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