Key Note Speech

MAPPING FROM SPACE

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ABSTRACT

Traditional mapping by photogrammetry has been successful to provide a near global coverage at the 1:200 000 scale. For the more useful scale 1:50 000 only 2/3 of the globe were covered, however, there is a serious lack of update of these maps in the developing world. Mapping from satellites can bridge the existing gap in providing timely information.

The paper lists the historical development of optical and radar satellite sensors. The present high resolution satellite sensors are more expensive than aerial photography products. In the future there will be competition to existing systems by small satellite operators. Advances in digital mapping technologies have led to the efficient creation of software systems for the restitution of aerial and satellite images. Radar interferometer technology has proved useful for small scale digital elevation model creation. The advantage of using satellite data is in its integration with data from other sources.

1. MAPPING

The objective of mapping is to provide a model of the earth's surface which can be used for the purposes of navigation and for depicting and for planning the natural and the socio-economic environment with the aim of a sustainable development. In historical times the progress of mapping was limited by the technical abilities for geocoding the features of interest on the earth's surface. In the old ages this has resulted in only local surveys of settlements. In the 14th and 15th century the emphasis was placed on navigational charts for the purposes of exploration. In the 17th century the method of triangulation permitted to determine distances via angular measurements. Paired with astronomic positioning this resulted in the first geocoded maps for area coverage of countries compiled because of military interests. It took at least a century to compile medium scale maps of the countries of Europe by terrestrial plane table surveys.

For the mapping of the vast non-European continents accurate mapping required a new technology. This technology has been made possible by the invention of the airplane in 1903, and by the invention of the aerial mapping camera in 1915. The technology of photogrammetry permitted to map entire continents during world war II. After 1945 the benefits of this technology have been applied to the developing continents of Latin America, Asia and Africa.

The U.N. Secretariat has followed worldwide mapping progress in its reports published in World Cartography. The 1990 status of topographic mapping in the scale ranges 1:200 000, 1:100 000, 1:50 000, and 1:25 000 has been summarized by the data contained in fig. 1.

Continent / Scale	Africa	Asia	Australia & Oceania	Europe	former USSR	North America	South America	World
1:200 000	89.1%	100%	100%	90.9%	100%	99.2%	84.4%	90.2%
1:100 000	21.7%	66.4%	54.4%	87.5%	100%	37.3%	57.9%	58.9%
1:50 000	41.1%	84%	24.3%	96.2%	100%	77.7%	33%	56.1%
1:25 000	2.9%	15.2%	18.3%	86.9%	100%	45.1%	7%	33.3%

Fig. 1: Status of Topographic Mapping

Fig. 2 lists the update rates of the map coverages shown in fig. 1:

Continent / Scale	Africa	Asia	Australia & Oceania	Europe	former USSR	North America	South America	World
1:200 000	10.9%	15.4%	2.9%	59.9%	-	51.9%	2.2%	3.4%
1:100 000	28.8%	0.2%	0.7%	55.9%	-	0.2%	0%	0.7%
1:50 000	18.4%	5.7%	13.1%	45.9%	-	21.4%	6.1%	2.3%
1:25 000	14.0%	27.7%	15.8%	52.5%	-	32.2%	0%	5.0%

Fig. 2: Update Rates 1980-1987 of the Global Topographic Map Coverage

The summary states that about 100 % of the land area of the world is covered by maps 1:200 000 for global requirements, about 2/3 by maps 1:50 000 for local needs. Most of these maps are in the process of vector or at least raster digitisation. But the crucial truth is, that most of the map information is not up-to-date. The world coverage of up-to-dateness of maps is more than 20 years old. The current updating procedures by aerial photogrammetry are either too costly or too slow to permit an up-to-date coverage of digitised map information. With the exception of Europe and the developed countries of the world this constitutes a serious problem for the developing countries.

For this reason a new technology for mapping and especially for map updating is most welcome. Such a new technology is mapping from space. Ever since the launch of the Russian satellite Sputnik in 1957 there has been an interest in imaging the earth's surface from space. With the US-NASA-NOAA satellites, starting with Tiros in 1961 meteorological data were gathered around the globe with a few to 1 km ground resolution. They served global meteorological and climatological requirements, but could usefully also be employed to monitor the status of global vegetation at bi-weekly intervals at low resolution.

The thematic mapping of resources began with the medium resolution US-Landsat satellite program with Landsat MSS in 1972 at 80 m resolution. This was improved with Landsat TM in 1982 at 30 m resolution, useful for monitoring the status of agriculture, of land cover and of forests. The medium resolution of 30 m also proved useful in monitoring catastrophic events such as floods, fires, and earthquakes. Since NASA's Seasat in 1978 and ESA's ERS in 1991 all weather radar systems supplemented this informations. More detailed information required for topographic mapping was in the 1980's governed by military resolution restrictions. These higher resolution satellite missions were based on camera technology used from manned and unmanned space platforms and from digital optical sensors, which since the French SPOT in 1986 have been improved in ground resolution down to 0.6 m at present.

2. OPTICAL SATELLITE SENSORS

The history of medium to high resolution optical sensors is shown in fig. 3.

(1968) 1998	Corona	3 m	Film	Stereo
1972	Landsat MSS	80 m	Digital	-
1982	Landsat TM	30 m	Digital	-
1983	Metric Camera-SL	10 m	Film	Stereo
1984	Large Format Camera	5 m	Film	Stereo
1986	Spot P	10 m	Digital	Stereo
1987	KFA 1000	7 m	Film	Stereo
1991	KVR 1000	2 m	Film	TK350(Stereo)
1993	MOMS 02	5 m	Digital	Stereo
1996	MOMS 02-P	6 m	Digital	Stereo
1996	IRS 1C/D	6 m	Digital	Stereo
1999	Ikonos 2	1 m	Digital	Stereo
2000	EROS A1	1.8m	Digital	Stereo
2001	Quickbird	0.6m	Digital	Stereo
2002	SPOT 5	2.5m	Digital	Stereo

Fig. 3: The High Resolution Optical System History (Optical Systems)

A systematic survey of high resolution imaging has been initiated by the US military Corona program in 1968. It was based on panoramic film cameras. In 1998 these images have been declassified. They are now available as inexpensive film products by the USGS. Overlapping images permitted stereo-restitution. The start of high resolution stereo-imaging was made by the German ESA Metric Camera experiment from Space Shuttle in 1983, in which about 10 % of the earth's surface was imaged in stereo with a ground resolution of 10 m. The US-NASA conducted another such experiment with the Large Format Camera LFG in 1984 reaching 5 m ground resolution in stereo. While Spot in 1986 with 10 m panchromatic resolution marked the beginning of Western digital high resolution sensor imagery, the Russian efforts of the 1980's and 1990's continued with optical film imaging system such as the KFA 1000 in 1987 with 7 m resolution and the KVR 1000 in 1991 with 2 m resolution.

In 1993 the first digital stereo sensor MOMS 02 was flown on US Space Shuttle with 5 m resolution. The missions were continued on the Russian MIR station from 1996 to 2000 with 6 m resolution. 1996 marked the year, when developing nations began to enter space imaging with the Indian IRS 1 C/D in 1996 with 6 m resolution. While digital stereo imaging at the highest achievable ground resolution is still carried out in the US military KH 11 and KH 12 programs the first U.S. commercial ventures have been launched by Space Imaging, with Ikonos 2 in 1999 at 1 m resolution. In 2000 Ofek of Israel launched EROS A1 as a 1.8 m satellite, and the U.S. Earth Watch with Quickbird surpassed the resolution up to 0.6m with a stereo possibility. Also the French launch of Spot 5 in 2002 with a 2.5 m resolution in an on-line stereo version is a step in this direction. Other efforts of high resolution imaging are planned by Japan with ALOS in 2004 with 2 m resolution, by China & Brazil with CBERS in 2004 with 2 m resolution, by India with Cartosat in 2003 with 2 m resolution. Earth Watch and Space Imaging have obtained licenses for 0.5 m resolution satellites for 2004/5.

3. RADAR SENSORS

The history of radar satellite sensors is shown in fig. 4.

year	name	country	agency	pixel	elevation accuracy
1978	Seaset	USA	NASA		
1991	ERS ½	ESA	ESA	12 m	5 to 100 m
1994	JERS 1	Japan	NASDA		
1995	Radarset	Canada	Radarsat Int	6 m	
1995	Almaz	Russia			
2000	SRTM-Cband	USA	NASA/NIMA	15 m	10 m
2000	SRTM-Xband	Germany	DLR	15 m	5 m
2002	Envisat	ESA	Astriun	12 m	
Proposed after 2004					
	High resolution System	Russia		1 m	
	Terrasar	Germany		4 m	
	Sar- Lupe	Germany		1 m	

Fig. 4: Radar Satellite System History

Radar images have the advantage of an all day, all weather sensing system, but object reflections behave very different from those received by optical sensors. They can supplement, but not replace optical images.

Satellite radar systems, however, have the advantage of coherent radar pulses. Thus not only the distance to the object, but also the phase of the incoming backscattered signal may be utilized to achieve a high azimuthal resolution, and moreover signals received at two antennas separated by a base may be utilized by interferometric principles to determine height. Particularly the two ERS 1 and 2 satellites, flown in a tandem mission in nearly the same orbit a day apart have been used to obtain interferometric heights. After phase unwrapping and reference to control these agreed within 5 m in unvegetated flat areas, but showed discrepancies of up to 100 m in areas of radar foreshortening and radar shadows. The Shuttle Radar Topographic Mission SRTM flown in 10 days by NASA/NIMA and DLR with 2 radar interferometers, separated by a long mast of 60 m length provided a nearly global interferometric radar coverage. The construction of higher resolution radars and interferometric system (the CNES/DLR Interferometric Cartwheel in conjunction with Envisat) is in sight for the next few years.

4. SMALL SATELLITES

The monopoly of expensive large mass satellites and platforms launched by governmental organizations has been broken by private initiatives to launch small satellites. As early as 1993 the laboratories of Surrey University cooperated with Korea and Portugal to launch mini- or micro-satellites, which are able to carry small satellite sensors. In 1999 the DLR Tulsat launched from India was able to experimentally reach 6 m ground resolution by an optical sensor. This was later repeated with UoSat 12 launched by Surrey in Russia with a 10 m resolution. Other attempts launching small satellites have been successful, such as Kitsat (Korea), Tiungsat (Malaysia) in 1999, and Tsinghua 1 (China) in 2000. Surrey claims, that small satellites can reach 95 % of performance of the conventional satellite platforms at 5 % of the cost and 70 % of performance at 1 % of the cost. A great number of small satellites is in preparation for launch in the next years as shown in fig. 5.

Mission	Agency	Launch	Resolution	Swath
Meisat	Korea		8.5 m	47 km
Khrurnichev	Russia		8 m, 3-5 m radar	
S. Res.Inst.	Russia		1 m radar	10 km
Rapideye	Germany		6.5 m	4 satellites
Tubitac	Turkey			
Rocsat	Taiwan		8 m	24 km
Hypseo	Italy		5 m pan	20 km
Topsat	UK		2.5 m	
Sunsat	South Africa		5-10 m	80 km
KAIST	Korea		2.5 m pan	20 km
Interferom.	DLR/CNES		1-3 m	
Cartwheel	For Envisat		radar interferometry	

Fig. 5: Planned Small Satellite Missions

5. DIGITAL MAPPING TECHNOLOGIES

The recent transition of photogrammetric technology from analytical photogrammetry, using computers for the traditional manual mapping tasks to digital photogrammetry, in which raster scanned images are used in digital form, has opened new ways for semiautomatic and automatic operations in the restitution process. Due to the capabilities of digital image processing image matching has permitted automation in measurement of points and in creating digital elevation models (DEM's) via image correlation. Based on these DEM's orthophotos can be calculated via resampling techniques according to collinearity equations. These equations can be easily modified for different satellite sensor geometries, so that the photogrammetric restitution process is no more limited to aerial photography.

For the geocoding of orthophotos and their tone-matched mosaics new inflight determinations of the coordinates of the exposure stations and the sensor orientation have been made possible by inflight differential GPS and by inertial measuring units. These positioning and orientation data may be adjusted and analysed for large blocks of images guaranteeing a geocoding accuracy to the sensed pixel with high reliability due to statistical checks applied.

Recently P/C based digital photogrammetric restitution programs have internationally been made available. One of the examples is SIDIP (Simple Digital Photogrammetry) developed at the University of Hannover. It contains the following features:
- semiautomatic point measurement of fiducial marks, transfer and control points in the photos
- sensor models for aerial and satellite sensors
- orientation by bundle block aerial triangulation block adjustment up to 6000 images and 200 000 points, with the possibility of incorporating GPS exposure station and INS orientation data
- generation of elevation models via image matching with filtering capabilities
- geocoded orthophoto generation
- tone matched mosaicking
- interpolation of DEM contours in raster and vector form
- side views of DEM's by wire frame models with a possibility of draped image superposition.

With this program Ikonos 2 mono and stereo images have been restituted for the less expensive Carterra products offered by Space Imaging for a price of 29 $/km2 in Europe (apparently special offers in the USA went as low as 7 $/km2). The Carterra product constitutes an image projected onto a plane tangent to a local ellipsoid in the area imaged. The resultant discrepancies away from the image center line along the orbit reflect the height displacements with respect to that plane. In mountainous areas they can result in discrepancies of up to 200 m.

If, however, ground control and a digital elevation model is available, then the resulting geometric discrepancies may be reduced by an affine transformation and the application of collinearity equations to less than 4 m. A similar result in accuracy may be achieved by stereo restitution of stereo Ikonos images.

This proves, that the expensive Space Imaging high accuracy products (100 $/km 2 and more) can be obtained by own efforts with appropriate software programs. One should realize, however, that aerial photography at an image scale 1:40 000 with 50 cm pixels can yield a superior result in tone rendition and interpretability, as well as in geometric accuracy of ± 1 m for 1:10 000 mapping at prices of 23 $/km2 for the entire process of aerial flight to aerial triangulation, image matching to geocoded orthophoto generation, which is less than the Carterra product without restitution.

6. COST FACTORS

The digital photogrammetric mapping cost can be assessed at the following international standard rates:

aerial photography 4000 $ mobilization plus 10 $ per image
scanning of photos 15 $ per image
aerial triangulation 25 $ per image
digital elevation model 120 $ per image
digital orthophoto 30 $ per image
mosaicking 20 $ per image.

On screen digitising by stereo-workstations or in the orthophotos is labour intensive, and it may vary with the details available, e.g. for rural areas 10 hrs/image to urban areas 100 hrs/image. This is why companies of developed countries with labour rates of more than 50 $/hour have entered joint ventures with institutions in low labour cost countries of less than 20 $/hour to extract GIS information from the images.

It should be noted, that pricing for a product consists of costs plus overhead plus profit plus risk. These factors, additional to cost determine the bidding scene for international projects.

In aerial photography the costs relate to the neat portions of a photograph, which is scale dependent.
With the photo size a' x a' = 23 x 23 cm the area covered by a photo is a x a, with ' $a=h/f * a$
(f = focal length, h = flying height).

As the photos are usually flown with a longitudinal overlap of 60 % and a lateral overlap of 70 % the air base b becomes b = 0.4 a, and the distance from flight strip to flight strip q = 0.7 a. Thus the neat model area becomes b x q = 0.28 a2. For a photo scale 1:13 000 the neat model area is 2.5 km2 and for aphoto scale 1:40 000 is 23.7 km2. When these photos are scanned at 15 µm this results in a ground pixel of 20 cm for the 1:13 000 image scale and of 60 cm for the 1:40 000 image scale.

According to the above cost data for 1:13 000 photography 20 cm pixel orthophotos may be produced at 180 $/km2. For 1:40 000 photography scanned at 12.5 µm 50 cm pixels will result. These orthophotos may be produced at 23 $/km2.

Line mapping of 20 cm orthoimages is possible at the scale 1:2000 at 1200 $/km2, and line mapping of 50 m orthoimages at the scale 1:10 000 is possible at 150 $/km2.

One of the relatively high cost factors is the generation of digital elevation models. The advantage of DEM's is that they generally do not change except through construction of catastrophic events. In the States of Germany they have traditionally been generated either by terrestrial surveys with ± 1 dm accuracy in a very expensive time consuming way, or by stereo photogrammetry with ± 2 dm to ± 5 dm accuracy.

Nowadays laser scanning permits to derive digital surface models (DSM) with ± 1.5 dm accuracy at costs higher than aerial photography, but with the advantage to receive tops of trees or buildings and ground signals for DSM and DEM generation for areas (planted forests, cities), where this seems to be required. Another less expensive, but lower accuracy alternative is airborne radar interferometry with accuracies in the ± 1 m range or satellite radar interferometry in the ± 5 m range.

With DEM coverages available from these sources digital orthophoto production may be reduced in cost.

7. INTEGRATED APPROACHES

Mapping from satellites is not an either or proposition. Its advantage lies in its capability for value added data integration. This was demonstrated in a DLR project for the design of a disaster relief information system for the region of Kosovo. To obtain timely information on the crisis region the following data sources were integrated into an information system:

- the topographic maps 1:50 000 of NATO
- the European CORINE land cover maps 1:100 000
- the ERS ½ interferometric DEM
- the most recent satellite imagery from Landsat TM, IRS 1C/D, KVR 1000 and Ikonos 2 subjected to visual interpretation and change detection routines
- these were supplemented by local low accuracy GPS surveys determining the damages on roads, railways and bridges
- local digital camera images for multimedia use for the assessment of damages to buildings.

8. CONCLUSIONS

The review on the possibilities for mapping from space leads to the following conclus ions:
- Mapping from satellites to 0.6 m pixel is a reality. This corresponds to 2 to 4 m object recognition which is required for 1:5000 image mapping.
- 0.5 m resolution is in sight in the future.
- At present high resolution satellite images are more expensive than aerial photography with equal performance; they are thus geared for a military market in areas, where aerial photography is not easily possible.
- In the future there is strong competition between big agency satellite systems and small satellites.
- 1 m radar interferometric systems and 1 m radar imaging systems are in sight for the supplementation of optical images.
- Orthophoto mapping is far less costly than line mapping.
- Data integration from all sources is a must.

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