THE APPLICATION OF SATELLITE DATA TO UPDATING NATIONAL DATA BASES

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ABSTRACT

This paper sets out the current position regarding the status of high resolution optical sensors on satellites. It concentrates on the American systems but puts these into the wider context of other sensors. The characteristics of the sensors are discussed and the products which are expected. The probable use of the data is presented as a case study which used simulated 1m data to derive digital elevation models and other products to the specification of the Ordnance Survey in UK. The work showed that images with 1m pixel size are not generally good enough for revising data bases at large scale. In the Ordnance Survey case this is digital data derived from 1:1250 maps, or heights from 5m contours with a required accuracy of ±1m. However the data can be used for smaller scale mapping and can also be used to extract buildings.

The paper conclude with a discussion on the role of automation and on such issues as availability and cost of the data.

1. INTRODUCTION

Many users in the Earth Observation community have been looking forward for some time to the launch of commercial, high resolution sensors developed in the United States of America. For many years SPOT has been the best sensor available to the civilian community even though some Russian data has been available and although during the past two years MOMS-02 on Priroda and IRS 1C have been launched with around 6m pixel size. The jump to 1m pixel size, with the great flexibility promised by the American systems, seems like the answer to everybody's dream. But without data we are still asking whether they will be as good as promised and whether we will be able to afford the data when it comes.

This paper aims to give some background to the development of the new sensors and to look at the possible uses of the data and the effect that this will have on the mapping community, particularly on national mapping organisations such as Ordnance Survey in Great Britain.

2. REQUIREMENTS

The current situation is that there is need for information for a wide range of applications including national mapping, telecommunications, planning and control by utility companies and local authorities, vehicle navigation and tracking and defence. However for many of these applications data from satellites will not meet the requirements. At the same time organisations concerned with the exploitation of satellite data are looking for new applications. The Centre for Earth Observation (CEO) at the Joint Research Centre of the European Union has set up a series of studies into the applications of Earth Observation in industries such as travel, insurance shipping and most recently, navigation and digital mapping. Organisations are also looking to be as efficient as possible and reduce costs. At the same time scientists are learning how to make better use of the data through a better understanding of the basic processes, through automation of processes, through better communications and better hardware so that a much wider group of people can access and use the data. Hence it is very clear why there is such an interest in 1m satellite data.

3. SENSOR CHARACTERISTICS

The new sensors will have a number of important features which are summarised in Table 1. Probably the most important characteristic is the pixel size, down to 1m for

System	Earlybird	Quickbird	Orbview	Space Imaging
Launch Date	Launched December 1997	1998	1999	1998
Sensor	Staring Array	Pushbroom	Pushbroom	Pushbroom
Sensor Position	GPS	GPS	GPS	GPS
Altitude in km	470	470	470	680
Side ways look in degrees	30	30	45	45
Pan sensor: Pixel size - Nadir	3m	1m	1&2m	1m
XS sensor number pixel size	3 15m	4 8m	4 8m	4 4m
B/H	1.2	1.2	2.0	2.0
Swath width	6km x 6km	36km	8km	12km
Accuracy (Z)	1.5m	0.5m	0.4m	0.4m
Stereo	In Track	In Track	In Track	In Track

Table 1. Summary of the main characteristics of the US high resolution sensors.

the panchromatic channel and 3m for the multispectral channels. The second most important feature is the stereo capability in both along track and across track mode with pointing angles of up to 45°. This will make the probability of obtaining stereo data much higher. The pointing accuracy will be high as will the positioning, through GPS. This will reduce the requirement for ground control points and make mapping and registration more efficient. Another benefit from the system is that value added products are expected so that the user will be able to purchase a Digital Elevation Model (DEM) or an orthoimage (image map) which will remove the need for intermediate photogrammetric processing.

The main problems at the moment perceived by the potential user are the cost and the old problem of cloud and availability. There is also uncertainty about what products will be available and whether sufficient information about position and attitude will be provided to customers for them to carry out their own processing on raw products.

4. PRODUCTS

There is clearly a wide range of potential products which include Digital Elevation Models and image maps as well as uncorrected panchromatic and multispectral data. Many value added products are possible such as classified images, difference images showing changes over periods of time, crop yields and many more. The possibility of extensive coverage of DEMs is very exciting to many people as it will allow images to be corrected for relief and topographic effects, hence permitting registration with other data such as SAR. However problems associated with generating DEMs at this resolution must not be minimised. With 1m pixels and intersection angles of 90° heighting accuracy from automatic image matching could be as high as 0.4m. But at this resolution the surface features such as buildings and trees, even vehicles, cause problems both in matching and interpretation. The pixel size is not small enough to allow buildings to be isolated and is big enough in urban areas to create problems from mixed pixels which will confuse the matching. Hence good algorithms are needed and robust validation procedures.

5. OTHER SYSTEM AND NEW DEVELOPMENTS

The main interest at the moment is in the American systems because of their novelty and to some extent the publicity but there are other systems available and planned. The first question to be asked is what is meant by high resolution. If we define this as a pixel size of less than 10m the Indian IRS-1C and German MOMS can be included. If we set it at less than 5m we are limited to the US systems discussed above plus the US/Israel EROS satellite, the French Helios and Russian systems such as KVR 1000 and KFA 3000 and new versions of existing sensors such as SPOT. There are other experimental US systems such as Clark.

The American systems have developed from military technology which has been put into the commercial domain by Presidential Directive 23 issued in 1994. This allows US companies to develop the high resolution satellite for commercial use in conjunction with non US partners and to offer the imagery onto the commercial market provided that the US government can control coverage at any time or place where US national security would be harmed. Most of these systems are small and cheap compared to the military reconnaissance satellites from which they are derived but are in line with the US National Reconnaissance Office's policy of more smaller, cheaper satellites offering more flexibility and lower cost.

Possible competitors to high resolution optical images are one pass interferometric SAR (IfSAR) from space or airborne systems such as IfSAR and LIDAR. Spaceborne IFSAR is currently unreliable but the Shuttle Topographic Mapping Mission planned by NASA and NIMA in USA, for launch in 2000 may improve the position. The airborne systems offer high accuracy but as yet are subject to similar costs as for aerial photography.

If this generation of satellite is successful we can expect more, small sensors in orbit offering greater choice and flexibility.

6. CASE STUDY: ORDNANCE SURVEY PROJECT ON HIGH RESOLUTION DATA FOR NATIONAL MAPPING

6.1 Background and requirements

University College London has collaborated with Ordnance Survey and the University of Southampton in a project partly funded by the British National Space Centre (Ridley et al, 1997 /1/) to investigate the use of high resolution satellite data for national mapping. The requirements of Ordnance Survey were as follows:

- filling in gaps in National Height Dataset (contours at 5m interval)
- automatic change detection
- topographic mapping
- Digital Elevation Models
- 3D building models
- national landuse database

The specification for Z in the National Height Data was given as ± 1m.

The possibility of satisfying these was investigated by using simulated satellite data with 1m pixel size. 1:7500 Aerial photography scanned at 25μm to give a 0.2m pixel size and this was averaged to give a 1m pixel size on the ground. ERS Interferometric SAR data was also used and data from the Compact Airborne Spectrographic Imager (CASI) was used to investigate the possibility of using multispectral high resolution data for a national landuse database.

6.2 DEM generation

A major aid for investigating all of these requirements was the DEM. These were created using three software packages, Zeiss PHODIS, LH Systems SOCET SET and the UCL 3D image maker (3DIM). This was done over three different terrain types. The results for the initial DEM generation using PHODIS and 3DIM as are summarised in table 2. The statistics were determined without any editing and by comparing the automatically generated DEM with the Ordnance Survey DEM derived from contours plotted at 1:10 000 scale.

Area - system	No points	Mean (m)	σ (m)	Min (m)	Max (m)
Agricultural area with motorway - 3DIM	23550	1.81	5.15	-7.99	24.89
Agricultural area with motorway - PHODIS	23550	2.04	3.71	-7.99	19.44
Urban area - 3DIM	30020	2.19	7.60	-8.00	25.00
Urban area - PHODIS	30020	2.36	3.23	-8.00	23.18
Agricultural area - 3DIM	24600	-0.29	3.13	-9.99	19.92
Agricultural area - PHODIS	24600	-0.03	1.55	-8.62	7.74

Table 2. Summary of results of DEM extraction of 3 areas with 2 DEM packages.

It can be seen that the precision of the DEM, shown by the standard deviation (σ), varies both with software and terrain. Taking the value of σ with the mean it can be seen that the biggest differences occur in urban areas and this is because the DEM including building is compared to the DEM of the ground surface. In agricultural areas a much lower mean is obtained but the standard deviation varies according to the amount of smoothing applied. To obtain a better idea of accuracy in homogeneous areas, small patches were selected and edited to give the results shown in table 3.

	No. of pts	Mean (m)	σ (m)	Max (m)	Min (m)
UCL 3DIM vs. PHODIS 0.2m	132	5.86	2.32	13.70	0.00
OS vs. PHODIS 0.2m	132	-5.34	2.29	0.16	-13.9
UCL 3DIM vs. OS DEM	132	0.54	2.22	10.31	-4.00

a. Statistics for patch A showing woodland.

	No. of pts	Mean (m)	σ (m)	Max (m)	Min (m)
UCL 3DIM vs. PHODIS 0.2m	529	3.23	0.56	4.26	0.70
OS vs. PHODIS 0.2m	529	-6.53	1.44	-1.87	-9.42
UCL 3DIM vs. OS DEM	529	-3.29	1.47	0.90	-6.70

b. Statistics for patch B showing bare ground.

Table 3. Accuracy of DEMs over small areas of homogeneous terrain.

These results show better precision although the means are still high, because of the vegetation.

These DEMs were tested for the above requirements to determine whether the elevations generated could be used for filling in cuttings and embankments along a motorway in the height data set, for providing elevations on new ground and for extracting buildings. The conclusions are given and discussed later.

6.3 Building extraction

The LH Systems SOCET SET was used to extract buildings in an urban area. A strategy can be selected which gives a small grid size and also which allows matching to take place over steep discontinuities such as buildings. The initial results allowed objects which stand above the ground surface such as buildings and trees to be identified and when an orthoimage was merged with the DEM buildings could be discriminated from trees. When building polygons, extracted from the National Topographic Database, were merged with the DEM values, could be assigned to the polygons showing, minimum, maximum or mean heights for the buildings. This in turn could be used to create perspective views. A sample of building heights was taken and gave root mean square errors of between 1.5 and 3m.

6.4 Synthetic Aperture Radar

Further tests were done with the ERS Tandem SAR data but although DEMs were produced using interferometric processing the results varies between 5.7m and 20m which is clearly not suitable for use within the National Height Dataset. Cloud cover was thought to have a significant effect on the elevations.

6.5 Conclusions

For all of these applications a set of conclusions can be drawn.

Creation of a DEM

- The automatically generated DEMs give the surface seen from the air and not the ground surface. This gives rise to the need for editing.
- The three packages tested with optical data give different emphasis: 3DIM gives finer detail and lacks editing facilities whilst PHODIS gives a smooth surface but has additional facilities for editing and use of breaklines. SOCET SET was best for building extraction.

Accuracy of the height data

- The requirement for a root mean square error of ±1m in height cannot be met at present with optical data. ±1.5 - 2m is a more realistic target for 1m optical stereo sensors assuming that editing is used and that the best base to height ratio is selected.

Detection of change

- Changes can be detected. However lesser accuracy and presence of non-surface features and errors does not allow matching to be carried out effectively.

Automatic generation of building heights

- Automation can be applied to generation of DEMs from 1m pixel size to extract building heights.

- Digital map data can be merged with the DEM and statistics calculated for building polygons.
  Building maxima has the most potential for defining buildings
  DEMs are needed at 1m or 3m spacing to extract buildings

- Heights of buildings can be determined to ±1m

Interferometric SAR

The results of the tests with SAR data showed that the data could not be used to meet the Ordnance Survey requirements but some useful conclusion could be drawn for future work.

- DEMs can be created from IfSAR with sufficient accuracy to determine significant deviations from surface defined by OS Land-Form Profile™ data such as motorway cuttings and vegetation.

- Night time pairs gave best results, there being significant atmospheric effects.

- IfSAR has potential for land cover analysis and this could be useful if used with optical data.

7. USE OF AUTOMATION

The availability of digital data at high resolution clearly offers the potential of introducing automation to some operations. If images from satellites are of the same type then they can be treated in a similar way to aerial photography and if necessary relative orientation can be carried out and 3-D co-ordinates generated. Boardman et al (1996) /2/, have reported on the Prototype Automated Image Registration System (PAIRS) which has been developed by Earth Observation Sciences Ltd, University College London, Technical University of Stuttgart and the University of Oporto, under contract for the Western European Union Satellite Centre (WEU).

This system for registration of two images of similar type adopts the strategy of selecting a large number of interest points in two images. From these two sets of points conjugate points are selected. The pairs of conjugate points are used to calculate a transformation from one image, the slave, to the other, the master. Within this transformation, procedures are built in to detect any erroneous matches which have escaped the checking procedure in the previous stage.

Methods have also been developed for registering satellite images to maps. For example Lee et al (1993) /3/, describe the REGGIE method which carries out a two dimensional registration. Holm et al (1995) /4/, has used lakes and islands in Finland as the features to use for matching and the method has been demonstrated with Landsat and SPOT data.

The work in the PAIRS project is being extended, with all of the partners in the WEU consortium plus KTH Stockholm and the Swedish Space Corporation, to develop the automatic registration of images to maps. This is the ARCHANGEL project funded under the European Union Fourth Framework research programme. The ARCHANGEL project aims at providing a generic, robust system for registering images from a variety of sensors to map data which may be originally in vector form or as a paper map which can be rasterised.

The method is designed for satellite images from which polygons can be extracted. The features to be used as control can come from a data base in which features are given attributes so that those with similar characteristics can be matched. For example a lake will have irregular boundaries and fields will have linear boundaries. It is not necessary to know whether the polygon is a field boundary or a lake or a building. All that is necessary is to extract an polygon from the image which will have a corresponding shape to an object in the reference data. The extraction of these polygons should be possible from any type of imagery, including SAR. An added attraction of this method is that any existing reference data can be used to assist in the detection of the features in the image. The method and progress to data has been described by Dowman and Ruskoné (1997) /5/.

8. DISCUSSION

The US satellite operators clearly have great faith in their product and the heritage of the sensors gives cause for some optimism. The greatest problem does seem to be the cost. Can commercial systems compete in the market with aerial photography and established photogrammetric systems which are nowadays made more accessible through the use of digital technology and automation? Table 4 shows some comparative costs for existing satellite data and aerial photography and costs of mapping.

It does appear that the new operators are going to be under some pressure to price data at the same sort of rate as SPOT in order to compete with aerial photography. This is also in the light of the fact that even 1m data cannot provide the same level of detail and accuracy as can aerial photography. Space Imaging is reported (Jane's International Defense Review 1/1997) to be targeting military customers, both in USA and elsewhere and no doubt hopes to support civilian sales in this way.

Besides the cost there is also the traditional concern of users of satellite data that weather conditions and programming conflict will limit the success in obtaining the required imagery when it is wanted. This problem is compounded by the fear of the US government exercising shutter control and cutting off the supply to civilian users.

Despite the conclusions drawn from studies with simulated data, there is still

Sensor	Cost /sq km data $	Cost /sq km ortho image and DEM $	Cost /sq km ortho image $
Aerial Photography 1:40 000	2.36	39.35	10 - 22
Aerial Photography 1:80 000	0.59	9.84	5.62
IRS-1C	0.50*		
SPOT pan	0.83	3.62	1.93
KFA 1000	0.47	2.04	1.09
KVR1000	2.5		
High res. data (Space Imaging)	10 - 15		

* 1996 figure.

Table 4. Costs for aerial photography, and satellite data. (From various sources including Spradley (1994), /6/.

uncertainty about performance of real high resolution optical data. The performance of the sensor when being constantly reoriented has not been experienced by commercial users, neither has the large tilts. Because only limited detail has been released on the sensor geometry and because software for handling the data has not been tested by end users there will be a need for exhaustive tests before the data can be used with confidence. A further concern is the amount of ground control needed.

Other issues which have been raised by users at the meeting 'Land satellite information in the next decade', held in 1995 and sponsored by The American Society for Photogrammetry and Remote Sensing include the quality and ease of use of the data. The data should be calibrated and quality clearly stated, especially for the value added products such as DEMs. Formats also need to be easily understood and standards should exists which are used by all suppliers. It is also important that users are given advice on software for extracting 3D co-ordinates and features from the data. There are also issues of handling large data sets, including data compression and image pyramids. Finally education is an important issue. If the data is really going to be applied by new users then these new users need to be educated in sensor technology and the processing systems.

9. CONCLUSIONS

It can be concluded from the information available and the studies carried out with simulated data that new data sources are coming and new tools are being developed to use them. Georeferenced and geocoded (orthoimage) products will be widely available and 1m optical data will be suitable for coarse mapping to give X Y Z co-ordinates in the 1 - 2m range but tools are still needed for efficient editing to remove blunders and unwanted surface feature data can be used with other data such as airborne SAR, laser profiling, multispectral data to contribute towards updating national databases. More work is needed on data integration and developing automatic tools.

Despite a number of concerns, there is real potential for high resolution optical data from satellites. If data can be obtained and distributed quickly and is competitive with aerial photography we may hope for the same catalytic effect which created a real interest in satellite data in the 1970s. This would boost sales and propel the Earth Observation industry towards a development phase which would lead to a mass market for the data.

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