High Resolution Space Imagery

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High-resolution imagery from space comprises optical imagery with a ground resolution lying within the range of 1 to 5 metres. Imagery of this quality has been available for some years taken by Russian agencies using photographic cameras mounted in recoverable satellites and operated on short-duration missions. Now a number of commercial high-resolution satellites equipped with digital CCD sensors and designed for a long operational life are due for launch in the near future. The main characteristics of the various systems producing high-resolution imagery from space are described in some detail. In particular, it is shown that the geometric characteristics of the new sensors and images are substantially different to those that are familiar to most users of aerial photos and existing low-resolution space imagery. This has particular implications for software development. Examples of high-resolution space imagery are given and comparisons made with aerial photographs of a comparable ground resolution. The main products and the potential markets for high-resolution space imagery are outlined. The wide range of likely applications of this imagery are also described and analysed. Finally, the issues that are likely to arise from the value-added products and services that the operators of the new systems plan to offer users are discussed.

Introduction

For some years now - ever since the U.S. government decided in March 1994 via Presidential Directive 23 to allow the development and deployment of commercial high-resolution satellites - the remote sensing and mapping communities have been awaiting the delivery of the first imagery resulting from this initiative. However, the actual development has taken much longer than was expected, especially given the considerable experience of many of the commercial companies that are involved in this new development - which had been gained through their supply of hardware and software for military satellite reconnaissance programmes. Furthermore the hopes of potential users have been dampened somewhat through the failures to launch and bring into operation those high-resolution satellites that have been built, e.g. Early Bird in December 1997, EROS-A in January 1998 and IKONOS-1 in April 1999. Notwithstanding these recent failures, sooner or later, high resolution space imagery will become available to users. Thus is relevant to discuss the characteristics of the different sensors and the resulting imagery and to discuss its potential applications.

One of the reasons for the removal of the previous restrictions by the U.S. government on the acquisition of high-resolution images from space by commercial agencies was the decision by Russia in 1987 to allow the sale of photography with ground resolutions of 5 to 10 metres taken from space for intelligence purposes using its KFA-1000 cameras. In 1992, the Russian authorities decided to allow the sale of the still higher resolution space photographs with a 2 metres ground resolution taken by its KVR-1000 cameras. Up till now, these Russian photographs have remained the highest resolution space images that are available to non-military users. They give a good idea as to what users can expect from the new commercial high-resolution space imagery, even though it is based on a different technology.

It is generally felt that the Russian initiative also helped to bring about the U.S. government's decision in 1995 to declassify and allow the public release of the huge archive of American reconnaissance photography taken from space by its Corona programme during the period 1960 to 1972. In fact, as researchers have discovered recently when inspecting this archive of 860,000 photos (now stored at the EROS Data Centre of the United States Geological Survey located in Sioux Falls, South Dakota), much of this photography also falls within the class of high-resolution space imagery with ground resolutions in the range 2 to 10 metres. The potential importance of this archive of historic imagery as a baseline for monitoring change in all sorts of different fields, especially those concerned with the Earth's environment, can hardly be exaggerated.

High resolution space imagery

Before continuing with a more detailed discussion of this topic, it seems appropriate to define what is meant by high resolution space imagery. Table 1 sets out six distinct categories of space imaging systems on the basis of the ground resolution of the resulting imagery taken with an optical sensor. Within this classification, very high-resolution imagery is defined as having a ground resolution

Class Number	Resolution Class	Ground Resol. (m)	Space Type	Photographic Agency	Camera Status	Space Type	Scanner Agency	Systems Status
1	Very High	<1	-	Military	Operating	KH-11, etc.	Military	Operating
2	High	1-5	Corona KVR-1000 KFA-3000	U.S.A Russian Russian	1960-72 Operating Operating	EarlyBird QuickBird EROS-A/B IKONOS OrbView	Earthwatch Earthwatch IAI/Core Spaceimaging Orbimaging	Failed 1997 * Failed 1998 Failed 1999 *
3	High/Med.	5-10	KFA-1000 TK-350	Russian Russian	Operating Operating	IRS-1C/D SPOT-1 to 4 Resouces 21 GEROS	Indian French Boeing GER Corp.	Operating Operating ** **
4	Med./Low	10-30	MK-4	Russian	Operating	MOMS-2P LISS-III Landsat ETM JERS-OPS ASTER	German Indian U.S.A Japan U.S.A/Japan	Operating Operating Operating Operating *
5	Low	30-300				RESURS-01 WiES	Russian Indian	Operating Operating
6	Very Low	>300				NOAA/AVHRR SeaWIES	U.S.A Orbimaging	Operating Operating

* = To be launched in 1999 ** = To be launched in 2000 or later

Table 1. Classification of space photographic cameras and scanner systems on ground resolution

of less than 1 metre. While most aerial photography taken for mapping purposes would come into this category, the imagery taken from space that falls within this range remains classified and wholly within the military domain. High-resolution imagery - the subject of this paper - comprises optical imagery with a ground resolution lying within the range 1 to 5 metres.

Classification of space sensors

Arising from the very different formats and products, it is also convenient to differentiate the available space sensor systems into two distinct groups within each resolution class. As shown in Table 1, these are:

(a) film cameras that generate images in the form of photographic films; and

(b) scanners that employ solid-state CCD detectors to generate images directly in the form of digital data.

Space cameras

Within the context of high-resolution imagery taken from space, in general terms, film cameras are normally operated in short-duration missions - usually of two to four weeks duration. This characteristic results from the necessity to recover the films which are of finite length and need to be processed to produce the required images and deliver them to the users. Normally space cameras are operated in a low earth orbit (LEO) of between 200 and 270km in order to get the best possible image of the ground. The exposed

Film Camera Type	Format (cm)	Focal Length (m)	Angular Coverage	Flying Height (km)	Ground Coverage (km)	Photo Scale	Ground Resol. (m)	Orbital Inclination	B:Ht. Ratio
KVR-1000	18x18	1.00	8.5x8.5°	220	40x40	1:220,000	2	67°	-
KFA-3000	30x30	3.00	6x6°	270	27x27	1:90,000	2-3	83°	0.04
KFA-1000	30x30	1.00	17x17°	270	80x80	1:270,000	5-10	83°	0.12
TK-350	30x45	0.35	46x65°	220	190x280	1:630,000	7-10	67°	0.52
MK-4	18x18	0.30	33x33°	280	160x160	1:930,000	10	83°	0.24

Table 2. Characteristics of space cameras and photography

Scanner System	Sensor Array Type	Orbital Height (km)	Swath Width (km)	Ground Coverage (km)	Ground Pixel (m)	Pointing Along Track	Cross Track	Orbital Inclination	B:Ht. Ratio
EXISTING SENSORS									
SPOT	Linear	822	60	60x60	10	No	±27°	98.7°	Up to 1.0
IRS-1C/D	Linear	817	70	70x70	6	No	±26°	98.7°	Up to 1.0
MOMS-02	Linear	296	78	78x78	13.5	±21.4°	No	28.5°	0.8
MOMS-2P	Linear	380/405	97/105	100x100	18	±21.4°	No	51.6°	0.8
IERS-OPS	Linear	570	75	75x75	18x24	0°/15.3°	No	98°	0.3
FORTHCOMING SENSORS									
EarlyBird	Areal	475	6	6x6	3	±30°	±30°	97.3°	Variable
QuickBird	Linear	470	36	36x36	1	±30°	±30°	52°	Variable
IKONOS 1	Linear	680	11	11x11	1	±45°	±45°	98.1°	Variable
OrbView3	Linear	460	8	8x8	1	±45°	±45°	97.3°	Variable
EROS-A	Linear	480	12.5	12.5x12.5	2	No	?	53°	-
EROS-B	Linear	600	16	16x16	1	Yes	±45°	98°	Variable

Table 3. Characteristics of space scanner imagery - Pan sensors only

photographic film may be recovered using special canisters that are ejected from the satellite. However, in the case of many of the Russian satellites, the whole satellite is recovered and the camera can then be refurbished and re-used. Whichever method is used, no ground receiving station is required.

The detailed characteristics of the Russian space cameras and the characteristics of the photography taken by them are set out in Table 2. From this, it can be seen that the KVR-1000 and the KFA-1000 cameras are those that produce high-resolution images - in the 2 to 3 metre class. Those taken by the KFA-1000 and TK-350 cameras fall into the class below, i.e. images having a high/medium resolution of between 5 and 10 metres.

Space scanners

In contrast to the situation with space cameras, the space scanners equipped with charged coupled detectors (CCD) are operated on a much longer term basis with a planned life of some years. Thus they have to be operated from much higher altitudes to ensure this longer life. They are also placed in very stable orbits that allow repetitive cover to be taken for monitoring purposes, besides providing more opportunities for images to be acquired during the periods of cloud-free conditions that exist above the target areas. Some space scanner systems have the capability to store their images on-board the satellites using a tape recorder or a large solid-state memory. These images are then retrieved by transmitting them to the ground when the satellite next passes over a suitably equipped ground receiving station. Other satellites employing scanner systems have no on-board storage system, in which case, the image data can only be acquired for those areas where the satellite comes within the view of a regional ground receiving station. To acquire wide coverage of the Earth's surface requires a large network of such stations.

The main characteristics of the space scanners and the resulting imagery are set out in Table 3. From this, it can be seen that none of the existing devices that are in operation produce imagery that falls in the high-resolution class - although the Indian IRS-1C/D sensors come nearest to doing so, producing imagery with a 6 metre ground pixel size. However the group of commercial high resolution satellites that are planned for launch over the next few years will all contain scanners producing images with a 1 or 2 metre ground pixel size.

Special characteristics of space imagery

It may be useful to set out the various special characteristics of space imagery and the particular conditions under which it is acquired as compared with those that are familiar to:

(i) photogrammetrists and cartographers accustomed to dealing with aerial photography within the context of topographic mapping and

(ii) planners and field scientists familiar with the use and interpretation of aerial photographs within their own disciplines.

(a) Flying heights are much greater with space imagery - lying in the range 200 to 900 kilometres above the Earth with space imagery, instead of the

1 to 12 kilometre range over which photographic aircraft are flown. At these high orbital altitudes, space images are often affected by clouds, whereas with aerial photography, it is often possible to fly below the cloud cover. This can be of particular importance if, for example, repetitive imaging is required for monitoring purposes.

(b) The focal lengths commonly used with optical imaging devices from space are usually very large to compensate for the high orbital altitudes and still give a good ground resolution. Typically focal lengths of 1 metre (in the case of the KFA-1000 and KVR-1000 cameras) to 10 metre (in the case of the IKONOS 1 sensor) are used, instead of the f = 8.5 to 30cm used with aerial cameras. This results in very narrow camera viewing angles - circa 1° for each of the new American commercial high-resolution satellites - compared with the 60° (normal-angle), 90° (wide-angle) and 120° (super-wide-angle) angular coverages of aerial photogrammetric cameras.

(c) In general, image scales are much smaller and ground resolution values are much larger (i.e. poorer) with space images as compared with aerial photographic images. At high resolutions, the area of the ground that is covered by space images is comparatively narrow. For example, the swath width of the imagery that will be produced by the Pan sensors of the new American commercial satellites is 6km with EarlyBird; 8km with OrbView and 11km with IKONOS 1. In this context, the view can be taken that the primary purpose of the new high resolution satellites will be to provide detailed coverage of specified targeted areas rather than the extensive coverage of large areas of terrain that has been a feature of the lower resolution imagery from existing satellites such as the Landsat series. Even then, one must remember that aerial photography is easily capable of producing ground resolutions in the low sub-metre class (0.1 to 0.5 metres) - which is better than any non-military satellite can achieve.

(d) Space imagery is quite inflexible and highly constrained in terms of the flight patterns that can be used. There is no free flying in the manner that can be practised by aircraft. However, some flexibility is provided through the use of the side pointing mirrors that are provided with some (though not all) space imaging systems. Also some additional flexibility is given through the use of “agile satellites”. These are equipped with motors and fuel to allow some small orbital corrections and adjustments to be made to bring the satellite into positions to image high priority targets. Up till now, this capability has been limited to large, complex military reconnaissance satellites.

(e) With space imagery, the orbital plane in which the spacecraft or satellite moves under the influence of gravity must pass through the Earth’s centre. Furthermore the orbital flight paths are related directly to the orbital inclination of the space platform on which the imaging sensor is mounted. In turn, this defines the possible ground coverage that can be acquired by the imager. For example, the MOMS-02/D2 coverage was limited to the area lying between 28.5°N and 28.5°S latitude - since the orbital inclination of the Space Shuttle for the Spacelab flight on which MOMS-02 was deployed was 28.5°. By contrast, the potential coverage of MOMS-2P lies between latitudes 51.6°N and 51.6° S - since the orbital inclination of the MIR space station on which it was mounted is 51.6° with respect to the Equator. Most of the new American high-resolution satellites will be placed in near-polar Sun-synchronous orbits giving coverage between latitudes 82° N and 82° S, though the QuickBird and the EROS-A satellites will have an orbital inclination of 52° (giving similar latitudinal coverage to that of MOMS-2P). This precludes the acquisition of coverage from these two satellites for all except the very southern part of Ireland lying south of latitude 52°.

(f) Much more stable operating conditions are encountered in space. In particular, there is no atmospheric turbulence producing unpredictable tilts and shifts of the type encountered with imaging sensors mounted on airborne platforms. These can cause quite severe geometric disturbances (such as gaps and double imaging) especially when airborne scanner imagery is being acquired. By contrast, the orbital characteristics of the platforms and sensors that are used to produce space scanner imagery - which have much more predictable motions - can be modelled mathematically with good accuracy using quite simple functions.

Photographic geometries

It is important for users to understand the geometric characteristics of high-resolution space imagery since it will be unfamiliar to most of them.

(a) Photographic cameras such as the Russian KFA-1000, KFA-3000, TK-350 and MK-4 examples produce planar-type images in the form of individual frames. These may overlap in the conventional way in the along-track direction to give stereo-coverage of the photographed area from a single flight (Figure 1). Each photographic image is acquired from a single exposure station in space with simultaneous exposure of the whole frame. This produces a central projection with a fixed orientation that applies to the whole photograph. However the KFA-1000 is often operated in a twin-camera, split-vertical configuration with each individual camera tilted by 8.5° to point obliquely to each side of the flight line (Figure 2). This is designed to increase the coverage of the terrain from a single flight.

(b) Provision has to be made within the camera for forward motion compensation (FMC) to be applied to the images acquired from space cameras since the satellite is moving over the Earth's terrain at a speed of 6 to 7km/sec. Thus, during an exposure time of 2 milliseconds (1/500th sec), the satellite will have moved 10m over the ground. If not compensated for, the image of a high-resolution photograph will be blurred. FMC can be applied either through movement of the negative film in the focal plane of the camera at a suitable rate or by rocking the camera as a whole through the required angular change to compensate for the satellite motion during the time when the shutter is open.

(c) Panoramic cameras such as the Russian KVR-1000 utilize a sequential line-by-line exposure of the frame using either a moving slit across the photographic film or a scanning mirror rotating in front of the camera lens. This gives rise to a cylindrical imaging surface (Fig. 3) and complex geometry with a new exposure station for each line of the image.

Space scanner geometries

It is important for users or potential users of the high resolution space imagery acquired by scanners to realize that the geometry of the imagery is very different to that of aerial photography or that of the familiar type of Landsat imagery. All scanner images are built up sequentially line-by-line using the platform motion over the ground to ensure coverage of the appropriate piece of terrain for each successive line of the image. This results in the exposure of a continuous strip image of the terrain instead of the frame-type images that are typical of photographic cameras. Optical-mechanical scanning of each new line was used in early scanners such as the MSS and TM devices used in the Landsat series. However, nowadays, almost all space scanner images are acquired using the pushbroom type of scanner employing linear arrays of CCDs (charge coupled detectors) to image a single complete line at a time. As noted above, EarlyBird is exceptional in using an areal (or staring) array of detectors - which produces an image that, in geometric terms, is similar to the planar image of a conventional frame camera.

Within pushbroom scanners, the main distinction lies in the method used to point the sensor at the ground - with particular reference to the acquisition of stereo-coverage, which is a feature of all the new commercial high- resolution satellites. Not only will this allow interpretation of the imagery in stereo (3D), but it will also allow the extraction of elevation information using automated image matching techniques to form a digital elevation model (DEM).

(a) **Cross-track configuration:** This makes use of a mirror that is rotatable in the cross-track direction only to provide the capability of imaging "off nadir". Under command from a ground station, the mirror can be rotated in steps to either side of the flight line or orbital track. Stereo-coverage is produced from two separate flights on adjacent tracks using overlapping images acquired with the linear array sensor pointing in opposite directions during the two flights (Figure 4). This configuration is already in use with the existing SPOT and IRS-1C/D satellites.

(b) **Along-track configuration:** This involves the use of two linear arrays of detectors, each tilted in a fixed orientation - the one pointing in the forward direction down the flight line and the other pointing in the backward direction along the same line (Figure 5). These sensors produce overlapping images of the same piece of terrain from different positions in space during a single flight. When the two images are used in combination, they provide stereo-coverage of the swath of the Earth's surface that has been imaged by the two sensors. This configuration has already been used with the sensors mounted on-board the MOMS-02 and JERS-OPS satellites.

(c) **Flexible pointing configuration:** This utilizes either gimballed mirrors or a whole body movement of the spacecraft. Whichever method is used, the sensor can be commanded to point in any direction at viewing angles of up to 45° from the vertical. This allows the acquisition of image data in both the cross-track and along-track directions or in any other intermediate direction (Figure 6). Stereo-coverage of an area of terrain can be acquired either from a single orbital flight or from adjacent orbits. This arrangement is a feature of almost all the new commercial high-resolution satellites.

With scanner imagery, each line of the image has its own individual and different perspective centre, instead of the single perspective centre for a complete frame image that exists for an aerial or space photographic camera. Besides the need to establish the three-dimensional coordinates of each of these individual perspective centres, it is also necessary to take account of the changing attitude or tilt of the space platform and its sensor over the time period during which the image has been acquired. Usually the preliminary values to carry out the required modelling of the orbital path and the orientation of the platform and its sensor are derived from the data generated by the auxiliary instruments such as GPS and inertial systems mounted

CAMERA GEOMETRIES

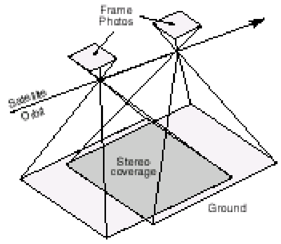

Fig 1

Aerial and space cameras.
Overlapping frame photographs.
Single exposure stations.
E.g. Russian TK-350 and MK-4

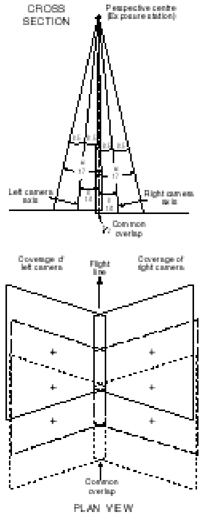

Fig 2

Split verticals (low oblique)
Overlapping frame photographs.
E.g. Russian KFA-1000 and KFA-3000

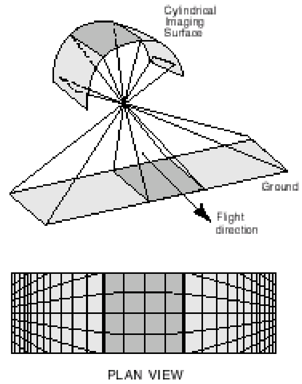

Fig 3

Panoramic camera.
E.g. Russian KVR-1000

SCANNER GEOMETRIES

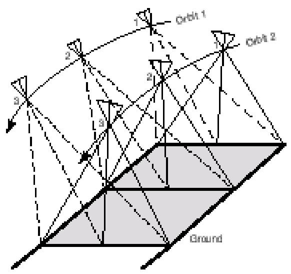

Fig 4

SPOT and IRS scanner imagery.
Overlapping images from two runs
(cross-track)

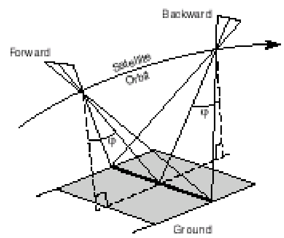

Fig 5

MOMS-02; JERS-OPS scanner imagery.
Overlapping images from a single run
(along-track)

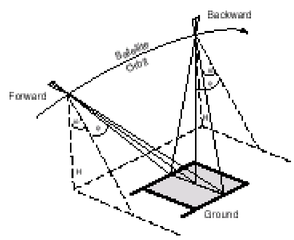

Fig 6

IKONOS, QuickBird scanner imagery.
Flexible pointing
(combines cross-track and along-track)

on-board the platform. Later these values are refined through the use of accurate ground control point (GCP) data, e.g. GCPs measured by GPS.

Need for new software

Virtually all of the new generation of non-photographic Earth Observation satellites are designed to use both along-track and cross-track modes of operation, in combination with linear arrays of CCDs, very long focal length telescopes and either precisely controlled gimballed mirrors or accurate pointing of the whole spacecraft. Whichever alternative is used, this last feature gives the possibility for flexible pointing (combining both cross-track and along-track pointing) of the imaging sensors towards the required target areas that will often lie to the side of the satellite ground track. This allows both stereo-coverage for elevation measurement and also repetitive coverage for change detection to be generated. However, at the moment, very little commercial (i.e. non-military) software is available from the photogrammetric and remote sensing system suppliers to allow users to handle along-track or flexibly pointed satellite imagery. It may be presumed however that the U.S. commercial satellite operators with their prior experience of supplying systems and services to American military reconnaissance and intelligence gathering programmes already have developed the necessary mathematical modelling and possess appropriate software and processing capabilities. But obviously the normal photogrammetric and remote sensing system suppliers will all have to develop a comparable capability to handle the new types of satellite imagery if they wish to compete in this market.

Characteristics of the new high resolution space imagery

For potential users, almost inevitably, the first questions will be what will the new high-resolution images look like and which particular features can be detected on the images. In practice, it is not too difficult to get some feel for what will become available. This can be obtained through an inspection of:

(i) the high-resolution space photography already available from the Russian KVR-1000 and KFA-3000 cameras with their 2m resolution; and

(ii) aerial photography taken in the scale range 1:40,000 to 1:60,000 scale which will have a ground resolution of 1 metre.

(a) In the case of the Russian space photographs, good examples with an Irish flavour are available on the Web site of the Eurimage company (http://www.eurimage.com/Products/KVR_1000.html). This comprises a KVR-1000 photograph covering the city of Dublin from the Howth Peninsula in the north to the port of Dun Laoghaire in the south and extending westwards to the M50 motorway (Figure 7). Also there are separate enlarged portions of this image on display. These cover;
(i) the area of Phoenix Park and Heuston Station (Figure 8); and
(ii) part of Dublin Harbour (Figure 9).
On these examples, one can see individual fishing and pleasure boats in the harbour and trains and larger types of road vehicles.

(b) Aerial photographs within the scale range 1:40,000 to 1:60,000 form the basis of the numerous simulations of the new high-resolution imagery that have appeared both on the World Wide Web and on sample CDs such as the Carterra IKONOS CD produced by the Space Imaging company.

Comparisons with aerial photography

Looking first at the matter of ground resolution, in the case of standard aerial photography at 1:40,000 scale, since 1mm on the aerial photographic image is 40 metres on the ground, then, with an image resolution of 40 lp/mm (line pairs per mm) on the photo, the minimum resolution of 1 lp/mm (=0.025mm) on the photo is equivalent to one metre on the ground.

Furthermore in making comparisons between aerial photography and space imagery, one should also consider the performance of modern aerial cameras such as the Zeiss RMK-TOP and Leica RC30 equipped with forward motion compensation (FMC) and gyro-controlled camera mounts, as used by the Ordnance Survey of Ireland and by BKS Surveys in Northern Ireland. These cameras can achieve an image resolution of 60 lp/mm when used with fine-grained photographic emulsions. In which case, with 1:60,000 scale aerial photographs, 1mm on the photo is 60 metres on the ground and the lens/film resolution of 60 lp/mm (equivalent to 0.017mm on the image) again gives a ground resolution of one metre.

In this type of comparison, it is worth keeping in mind that the ground pixel size of one metre quoted for the new space sensors will probably give rise to an actual ground resolution of nearer two metres - since the two measures of resolution are related to one another by the Kell factor by which two pixels are equivalent to one line pair (lp).

The areal coverage of the new space imagery will also be similar to that of the 1:40,000 to 1:60,000 scale aerial photography:-

(i) At 1:40,000 scale, a standard format 23 x 23cm aerial photograph covers an area of 9.2 x 9.2km.

(ii) At 1:60,000 scale, a standard format 23 x 23cm aerial photograph covers an area of 13.8 x 13.8km.

By comparison, a single IKONOS space image will cover an area of 11 x 11km, so once again, in coverage as well as resolution terms, it will give a similar performance to that of aerial photography in the 1:40,000 to 1:60,000 scale range.

Products

The suppliers of the new high-resolution space images intend or expect to supply imagery in the form of ortho-rectified images. These have had the displacements due to tilt and ground relief that were present in the original or raw images removed. Also they will offer so-called “pan-sharpened” images which will combine, i.e. merge together, the panchromatic image data with its 1 metre ground pixel size and the corresponding multi-spectral image data with its 4 metres ground pixel size that has been taken simultaneously. In addition, digital elevation models (DEMs) and contour maps will be generated from the stereo-imagery.

Fig 7 A KVR-1000 high-resolution space photo of Dublin stretching from the Howth Peninsula in the north along the coast to the ferry port at Dun Laoghaire in the south. At the top (north) is the International Airport. To the west is the M50 motorway. (Source: Eurimage)

Fig 8 This is an enlargement of the inset showing Phoenix Park together with Heuston Railway Station.

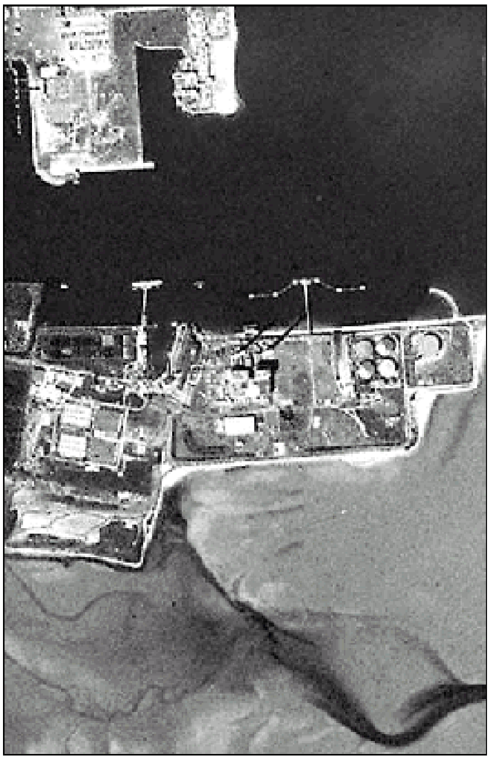

Fig 9 This ia an enlargement of part of Dublin Harbour showing the oil refinery. Some small vessels are also visible.

Markets

It is interesting to speculate on the various markets for these products - though it is not easy to do so in the absence of actual examples and of a definitive price list that would allow proper comparisons to be made with aerial photography and the products derived from them. Many commentators believe that foreign governments will be major customers, both in relation to development projects within their own country and for national and regional security purposes. In certain war-threatening circumstances, one can be fairly certain that there will be a cut-off in the supply of such imagery to certain powers. Indeed this may well be the case even in peace time. For example, it is extremely doubtful that those countries encouraging or supporting state-supported terrorism will be supplied with this type of high-resolution imagery. Though doubtless much ingenuity will be exercised in getting round any restrictions or bans on the supply of imagery to these countries.

A substantial new market is expected to develop in the form of the media (TV companies, newspapers, etc.) with their requirements for near real-time news gathering. Thus it is thought that images of areas suffering from natural disasters such as floods, tornados, forest fires, volcanic eruptions, etc. will be eminently newsworthy. In tandem with this comes the planning of responses to such disasters and emergencies which can be assisted greatly through the timely supply of suitable images to the appropriate state or regional authorities and agencies.

Applications

Turning next to the more traditional civilian applications, it is interesting to read the lists of potential applications that have been provided by the operators of the new commercial high-resolution satellites, backed up by sample simulated images.

(a) **Cartography** - in particular, that is associated with topographic mapping and map revision - is seen as a potential market. In this respect, it should be possible to enlarge and produce ortho-rectified images at scales up to 1:25,000 scale or even larger - as can be done with the corresponding aerial photographs. However, if change detection and the extraction of small terrain features are requirements, as in the case of map revision at medium scales, then it is not certain that these can be met by the new high-resolution space imagery.

(b) **Precision farming** and the monitoring of crops are also seen as potentially important markets for the new imagery with frequent updates for comparatively small areas (e.g. individual farms) being possible with a view to an analysis and estimate of crop growth and yield and the early detection of plant disease - cloud permitting!

(c) **Forestry** is seen as a potential area, again with a view to the detection and monitoring of areas of windblown timber, the estimation of timber volumes and the early detection of disease.

(d) **Environmental monitoring** is regarded as being another potentially important application with particular respect to the repetitive coverage that could be made available for coastal and estuarine studies, land use/land cover distribution, opencast mining, etc.

(e) **Planning** is seen by the suppliers as a promising field with regard both to rural and overall urban planning studies, as well as the peri-urban areas surrounding cities. Certainly one can see this as a really important application in the developing world where so many cities are simply exploding with many informal and unplanned settlements and the actual situation on the ground is simply not being recorded on existing maps of those cities.

(f) The high-resolution imagery can also be considered for use in **exploratory surveys** for minerals and for oil and gas deposits. Often these will be carried out in more remote areas for which existing maps will be at small scales and often lack the detail needed for interpretation, planning and navigation purposes.

Value added services and products

The matter of providing a value-added service or product from space imagery is one that appears likely to come to the fore with the introduction of the new high-resolution satellite imagery with its one to five metre ground pixel size. Some of the data acquisition and supply companies, e.g. Space Imaging EOSAT and its regional affiliates, envisage that much of the product that they will be supplying will be in the form of seamless mosaiced ortho-rectified imagery, DEMs, contour maps, perspective views, fused pan and multi-spectral images, specialized thematic maps and vector and raster data suitable for use in geographic or land information systems. Thus they envisage that they will be supplying highly processed data that is “GIS ready”. In which case, they will be undertaking both the photogrammetric processing and the thematic interpretation for their clients. EarthWatch also plans to offer a similar range of products from its Digital Globe archive to those offered by Space Imaging EOSAT. Furthermore the company has stated that “it will retain ownership and possession of all data collected by its satellites”. ORBIMAGE appears to have a somewhat similar strategy offering a range of standard value-added products through its international network of distributors.

Potential user reactions

Obviously the first question that will occur to users and potential users is whether the new commercial companies do indeed have the resources and management skills to generate, in a timely fashion, all the value-added products that customers will demand. If indeed, in practice, the supply of value-added products and services does become the major part of these companies' business, then this will be a big departure from present practice where space image data is commonly supplied either in its raw form or with basic geometric corrections only. Thus the users mainly undertake the further processing themselves employing their own specialist staff with their detailed knowledge of local conditions. They will find it difficult to believe that the operators of the new high resolution satellites possess the same expertise and local knowledge as themselves. This could become a real issue or, at least, a matter of debate.

Furthermore not only is space imagery expensive in itself, but a very substantial additional cost will be incurred in the conversion of the image data into map form or some other type of geospatial data - since basically information extraction from any type of imagery is a very expensive operation. This is especially the case if detailed point and line data needs to be extracted for topographic or thematic mapping purposes, since this invariably needs extensive human interpretation and measurement as well as local knowledge of the terrain. Thus it remains to be seen how users will react if they find that the costs of purchasing value-added products from the satellite operators and data suppliers is going to be very substantially greater than that of buying raw imagery or imagery with basic geometric corrections. Finally one cannot imagine that the photogrammetric and remote sensing system suppliers will be very happy with such a scenario either - since much of their software and expertise would then be by-passed.

Conclusion

As this paper has endeavoured to show, the future for high-resolution imagery from space of a quality and geometry that is much superior to that currently available is intriguing to say the least. In particular, it will be most interesting to see how it fares in competition with aerial photography of a similar quality and coverage.