Satellite Capabilities and Orbits

Bhupendra Jasani

1 Introduction

A mission of a satellite determines the type of orbit in which it is placed. Figure 1 shows satellites with different orbits. Usually, earth observation satellites, the focus of this chapter, are placed in near earth orbits at heights between 200km and 700km. Spacecraft closest to the surface of the earth are used for defence purposes as sensors on board such satellites could achieve maximum details. Civil remote sensing satellites listed in Figure 2 are orbited at altitudes between 400km and 700km. One of the most important applications of such satellites is for improving national and international security by monitoring bilateral and multilateral agreements, such as arms control treaties, that affect security.

It is often argued that in order to carry out the monitoring of arms control treaties, peace keeping operations, early warning of conflicts and even ongoing conflicts that often result in large movements of refugees (who also have to be monitored in order to deliver, for example, aid to them), many satellites would be needed. However, it can be seen from Figure 2 that there are already several spacecraft in orbit with optical sensors that have useful ground resolution of one metre and better. As these are launched and operated by different States, the satellites appear to be scattered and their orbits are such that observations of the earth cannot be made frequently enough and in any logical fashion. An examination of the orbital parameters of these spacecraft indicates that some are in one orbital plane and others move in orbits that are spaced out widely. The satellites are also widely dispersed relative to one another in their respective orbital planes. This means that a more frequent and wider coverage is possible but often randomly targeted.

It is, therefore, useful to consider some basic orbital mechanics and then to present results of the operation of some of the current commercial satellites listed in Table Figure 2. In the subsequent chapters, typical signatures or a "key" of targets, such as the various elements of the nuclear fuel cycle, are described. Also various image-processing methods are discussed. These

B. Jasani et al. (eds.), *International Safeguards and Satellite Imagery*
DOI: 10.1007/978-3-540-79132-4_2, © Springer-Verlag Berlin Heidelberg 2009

processes assist in the enhancement of images so as to enable the maximum extraction of data, which is used in combination with the key resulting in the efficient interpretation of images.

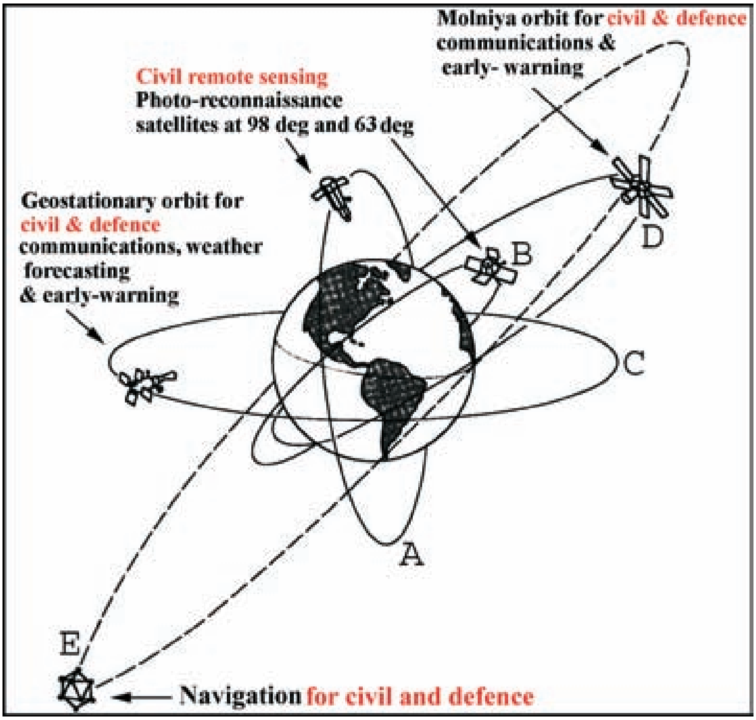

Fig. 1. *Various satellite orbits for different missions are depicted in this diagram. Source: [1]*

2 Some basic orbital mechanics

A satellite orbit is usually elliptical with the centre of the earth at one of the foci of the ellipse (see Figure 3a). There are six basic parameters, called the orbital elements , which completely describe the size, shape and orientation of an orbit of a satellite. Of these, Ω, the right ascension of the ascending node (RAAN) , ω, the argument of perigee (AoP) and i, the orbital inclination, are relevant for the present discussion. The position of the orbital plane in space is usually given in a terrestrial sidereal rectangular co-ordinate system, the axes of which are shown in Figure 3b. The origin, O, of the co-ordinate system is the centre of the earth; the z-axis is oriented towards the North Pole and the earth's equatorial plane is in the xy-plane. The x-axis is oriented towards

Country Satellite	Date of launch of satellite	Satellite altitude (km)	Resolution in pixel size (m)	
			Pan-chromatic	Multispectral
France SPOT-5	040502	822	2.5	10
India IRS-1C,-1D Cartosat 2 Cartosat 2A	241295, 290997 100107 280408	817, 780 630 635	5.8 less than 1 less than 1	23.6
Israel EROS-A1 EROS B1	051200 250406	~ 500 508	1.8 0.7	
Russia Resurs DK KVR-1000	150106 1984-92, 1998, 2000	360 x 604 200-260	1 2	2-3
UK TopSat	27 October 2005	700	2.5	5
USA				
KH-1 to 4	June1959-Dec63		7.6	
KH-4A	Aug1963-Oct69		2.7	
KH-4B	Sept1967-May72	705	1.8	30 & 120 thermal
KH-6	March1963-Jul63	705	1.8	28.5 & 60 thermal
Landsat-5	010384	680	-	3-5
Landsat-7	150499		15	
IKONOS-2	240999		0.8-1	
QuickBird-2	18 October 2001	450	0.61	2.44
WorldView-1	180907	496	0.5	
Orbview-3	260603	470	1	4
Earlybird-1	241297		3	15
ASTER	181299	705		15(bands 1-3), 30(bands 4-9), 90(bands 10-14)
EO-1	211100	700	10	30(9 bands) 30(220 bands)

Fig. 2. *Current commercial optical satellites showing the improvement in spatial and temporal resolutions since 1959*

the Vernal equinox or the first point of Aries[1]. The point of intersection of the satellite ground track[2] with the equator is known as the ascending or descending node. In Figure 3b, it is marked N so that the line ON is in the equatorial plane.

The angle Ω between the x-axis and line ON defines the RAAN and hence the orientation of the orbital plane of a spacecraft. During the lifetime of a satellite, Ω does not remain fixed. The rate of change of RAAN is given by

[1] The orbital plane of the earth is called the plane of the ecliptic. The angle between the earth's equatorial plane and the ecliptic plane is 23°7’. The line of intersection of these two planes defines an important direction in space, known as the point of Aries. At any particular time this direction is exactly known and all celestial directions can conveniently be referred to it.

[2] This is the projected path traced out by a satellite over the surface of the earth.

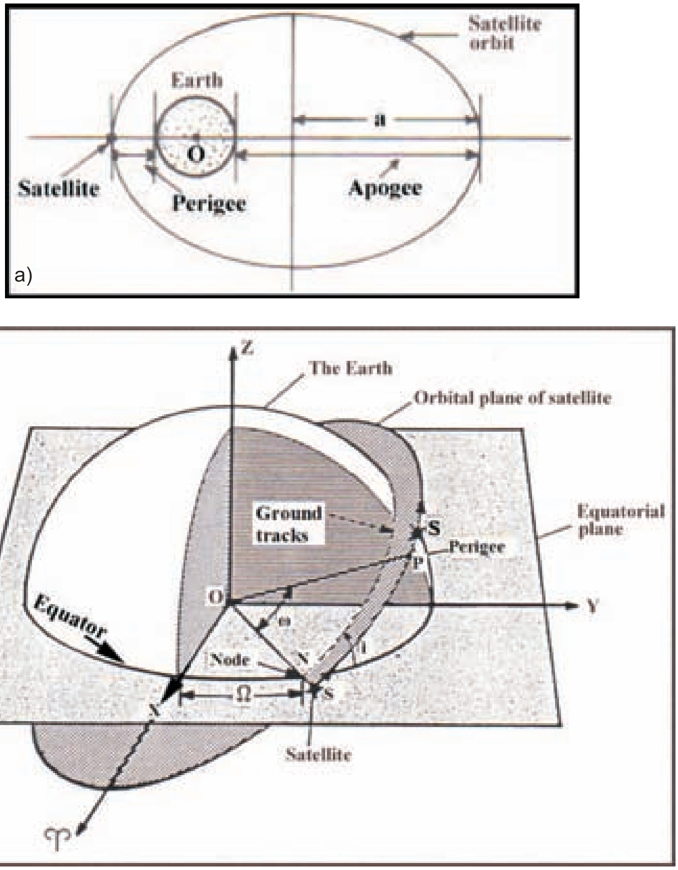

Fig. 3. *Geometry of a satellite orbit is shown in the figure below. Source: [2]*

the following equation [3]:

$$d\Omega/dt = [0.58644 R_{eq}^2/(1-e^2)^2 a^2] cos(i) \quad (1)$$

where R_{eq} is the radius of the Earth's equatorial plane, e is the eccentricity of the orbit and a is its semi-major axis.

If the orbital inclination i is 90°, then $cos(i)$ is zero making the rate of change of Ω zero. Thus, one can compare, for a particular day and time, the relative positions of orbital planes of various satellites. All the satellites (see Figure 2) considered here are in circular orbits with inclinations of just over 90°(see Figure 3). For observation satellites, the change in Ω is used so that they pass over a region of interest on the earth at the same time of the day throughout the active lifetime of the satellite. Therefore, the reconnaissance photography always refers to the same local time so that changes in activity in the region can be compared from day-to-day. The plane of the satellite orbit contains both the earth and the Sun. In this case the orbit is called a Sun-synchronous orbit. In this type of orbit, the satellite crosses, for example, the equator, at just about local noon on the sunlit side of the earth and local midnight on the dark side. Thus, most observation satellites are orbited in Sun-synchronous orbits.

The earth rotates under the satellite orbit, which is fixed in space, at a rate of 15° per hour. The orientation of the ellipse within the orbital plane of a satellite is given by ω, the second of the two orbital elements considered. It is the angle between the line ON (see Figure 3) in the equatorial plane and the line OP, where P is the perigee. The line OP always lies along the major axis of the ellipse. Because the earth is oblate, ω changes except for one value of orbital inclination (63.4°) at which it is constant. This means that the major axis of the orbit rotates in the orbital plane in the direction of motion of the satellite. Also ω could indicate the location on the earth being observed, as perigee is the closest distance between the satellite and the surface of the earth.

The range of latitudes over which the satellite travels on each revolution is determined by the third element i. It is clear that in order to observe every part of the globe, it is necessary to use a polar orbit with orbital inclination of 90°.

3 Comparison of orbits of some remote sensing satellites

In Figure 4, some of the orbital elements considered above for the Israeli, the French and the US (Figure 4a), and the Indian (Figure 4b) satellites are summarised.

From Figure 4a, it can be seen that while the Israeli, French and the US satellites are in orbital planes (as given by RAAN) that are close together, those for the Indian satellites are markedly dispersed (see Figure 4b). For example, the average value for the RAAN for Israeli, French and the US satellites is 297.86 (excluding Orbview 2 satellite) with one standard deviation of ±4.21, while for the India satellites these are 274.9117 and ±27.87 respectively. These values were analysed for different days and were found to follow the same pattern since their orbital inclinations are very similar (average 98.13 with standard deviation of ±0.51) and, therefore, the RAAN is not expected to change significantly throughout the life time of the satellites.

Using the Association for Geographic Information's (AGI) STK version 8.0.2 (2007) software, orbits of the above spacecraft were plotted. Examples of some of these are shown in Figures 5 and 6. From Figure 5a, it can be seen that the orbital planes of the Israeli, French and the US satellites are very close to each other. This is more clearly illustrated in Figure 5b when viewed over the North Pole. Orbits of Indian satellites were generated in the same way. These are shown in Figure 6. From this it can be seen that the orbital

Satellite	RAAN	AoP	i	Mean motion (rev/day)	Time
Landsat 5	294.2135	38.5678	98.1908	14.57124130	226.71598403
EO-1	292.9447	251.0842	98.1248	14.61666395	226.84370322
Ikonos 2	301.1900	78.4060	98.1085	14.64447512	226.74213720
EROS A1	293.6352	156.1439	97.4015	15.21604407	226.96239779
QuickBird 2	305.3511	112.2438	97.2085	15.39867881	226.78166207
SPOT 2	299.7271	34.3880	98.6845	14.20048900	226.75591875
SPOT 4	300.0791	72.6658	98.6962	14.20042606	226.79778240
SPOT 5	298.8895	117.8416	98.6840	14.20047987	226.89804877
Orbview 2	337.8399	118.3943	98.2810	14.59900985	226.39088682
Orbview 3	294.7094	64.6569	97.1471	15.38177249	226.78876020

(a) Isreali, French and US satellites

Satellite	RAAN	AoP	i	Mean motion (rev/day)	Time
IRS 1C	255.6456	90.9278	98.3764	14.21762570	226.56505896
IRS P3	228.3327	46.7276	98.3279	14.21632840	226.63499905
IRS 1D	280.9174	136.9597	98.3363	14.32909149	226.71673109
IRS P6	299.8137	278.7057	98.6819	14.2164242479	226.75628298
Cartosat 1	298.5711	88.0285	97.8361	14.82675663	226.76199621
Cartosat 2	286.1899	63.0447	97.9779	14.7861280	226.74025099

(b) Indian satellites

Fig. 4. *Four orbital elements for some of the Indian (b) and Israeli, French and US (a) satellites are shown in the following Tables for day 226 in 2007*

planes of these (Figure 6a) are spread out. Again this becomes more obvious when the orbits are viewed from the North Pole (Figures 6b).

The fact that the orbital planes of the Indian satellites are widely dispersed suggests that their revisit time over a particular target might be shorter in comparison with the other satellites. This is particularly true since the spacecraft can be tilted.

While the Israeli, French and US satellites are in almost the same orbital plane, their perigee positions are different. This is well illustrated in Figure 7 and 8 in which the locations of these spacecraft are plotted using the Satscape freeware programme for tracking satellites. With this programme it is possible to predict accurately the position of any satellite in orbit around the earth [4]. It can be seen that all of these satellites follow a specific track. The spread of these indicates the positions of their perigees. A similar plot was generated for the Indian spacecraft. In this case the satellites appear scattered all over the

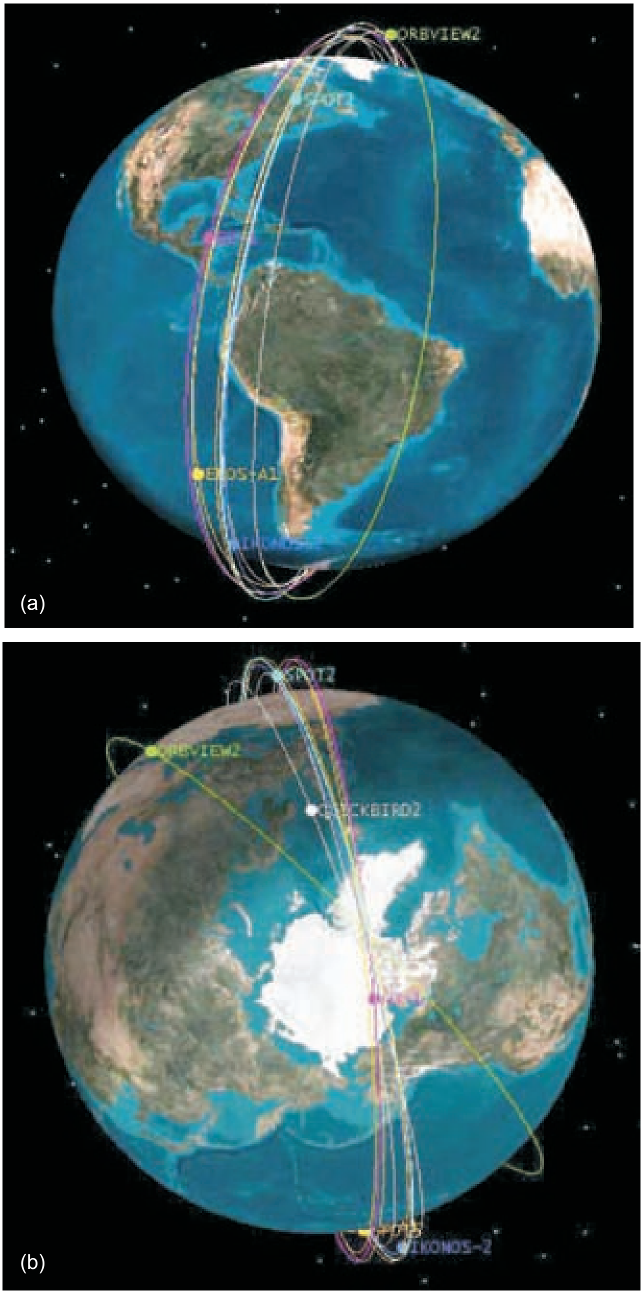

Fig. 5. *Orbits for some of the Israeli, French and US remote sensing satellites were generated using the AGI software (version 8) provided by STK for the day 226 in 2007; (a) shows a view from the front of the earth and (b) shows the orbits viewed from the north pole of the earth*

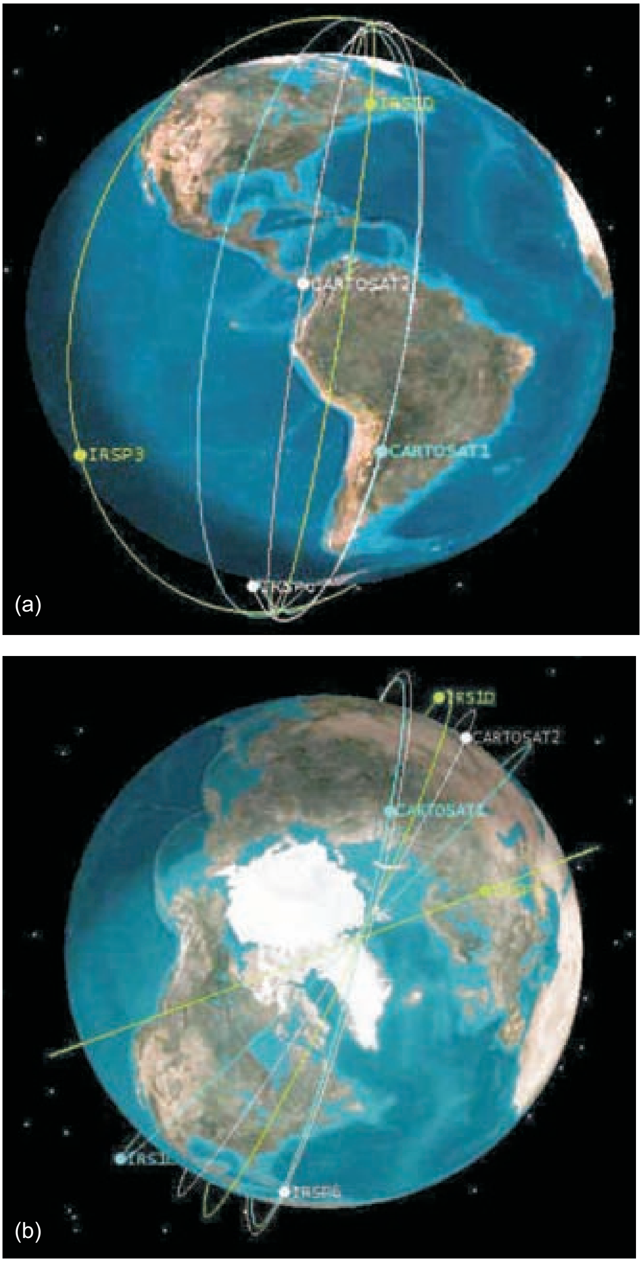

Fig. 6. *Orbits for some of the Indian remote sensing satellites were generated using the AGI software (version 8) provided by STK for the day 226 in 2007; (a) shows a view from the front of the earth and (b) shows the orbits viewed from the north pole of the earth*

Fig. 7. *Satellite orbits and positions were generated using Satscape freeware for the Israeli, French and the US satellites. With the exception Orbview 2, all spacecraft are in close orbital planes. The spread within the plane shows different perigee locations of the satellites*

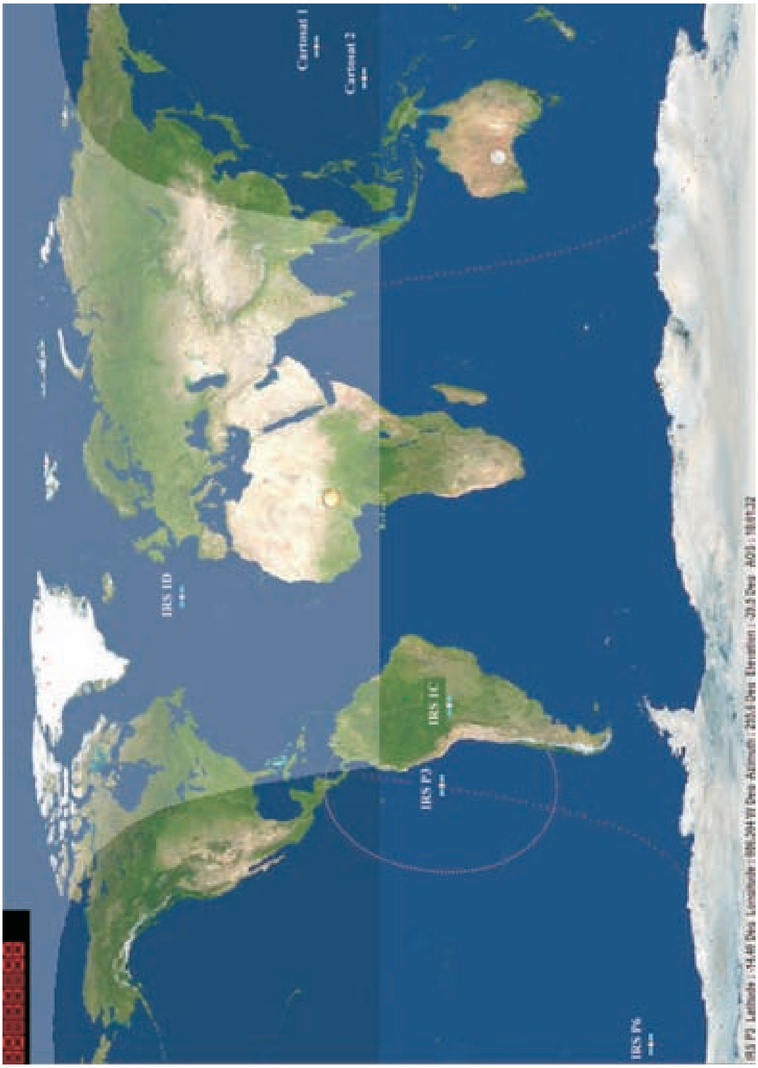

Fig. 8. *Satellite orbits and positions were generated using Satscape freeware for the Indian satellites. In this case it can be seen that orbital planes are well separated and the perigee locations are also well distributed*

globe as expected since their orbital planes are widely dispersed and of course their perigees are different as indicated by the positions of the satellites.

The conclusion of the above analysis is that with the constellation of the Indian satellites, they are more likely to have frequent revisit times over a particular target on the Earth. Whether this is deliberate or not, it is difficult to say but it certainly shows a way in which such spacecraft should be deployed if frequent observations of a target are to be achieved. This is so if all commercial remote sensing satellites were to be orbited in this way in cooperation with each other. Such a cooperation has already been suggested as early as 1991 [5].

4 Capabilities of commercial remote sensing satellites

The USA launched its first military observation or the so called spy satellite in 1960. This was followed by the then Soviet Union when it launched a similar spacecraft only two years later in 1962. However, these facts were closely guarded secrets until both Presidents Lyndon Johnson and Jimmy Carter acknowledged that the USA had been using satellites to collect intelligence information using their artificial earth orbiting photographic reconnaissance satellites [6].

A significant development occurred when, in 1990, Russia began selling high quality data acquired from their military observation spacecraft. These were degraded to ground resolution of between 1m and 2m by scanning the photographic films acquired from the Russian defence satellites. Such a degraded image over a military helicopter base in Germany is shown in Figure 9.

The image was purchased from Sovinfomsputnik as a positive transparency that was then digitised. The quality of the image was such that even when a small section of the image (where the helicopter base was detected) was enlarged, considerable amount of details were retained. For example, several helicopters deployed on the base could be clearly seen. Not only this, but in some cases the propeller blades could also be identified. The emergence of such images in the commercial market may well have prompted President Clinton to sign in 1995 an Executive Order [7] directing the declassification of intelligence imagery acquired between 1960 and 1972 by some of the early generation of US photoreconnaissance satellites. Only images acquired by these satellites were then commercially available. The best images with a resolution of between 10cm and 15cm are from the more advanced version of the Key Hole (KH) satellites, KH-11 and KH-11/Improved versions or KH-12 but these are still classified.

During late 1990s, the US decided to develop the Ikonos series of satellites that can acquire images with a ground resolution of between 0.81m and 1m. The first successful launch of such a satellite was Ikonos-2 on 24 September 1999. Both Japan and India have satellites in orbit with similar capabilities

Fig. 9. *An image over a German helicopter base was photographed by a Russian military satellite. Several helicopters can be detected and in some cases the propellers can also be seen.*
Source: KVR1000/ Sovinformsputnik

but data from the Japanese Information Gathering Satellites (IGS) are not commercially available. In fact, the orbital elements of these spacecraft are not openly available either. On the other hand data from the Indian satellite are now commercially available. India launched its 1m resolution Technology Experimental Satellite (TES) on 22 October 2001 [8].

On 18 October 2001, the US successfully launched its new generation QuickBird-2 commercial civil remote sensing satellite. The spatial resolution of the panchromatic and the multi-spectral sensors on board the spacecraft are 0.61m and 2.44m respectively. This brought the capabilities of commercial observation satellites close to those of, for example, the US KH series of military satellites that were in orbit until the mid-1980s. An example of an image acquired by the QuickBird-2 satellite over an airfield east of Nyala in Sudan is shown in Figure 10. A helicopter standing on the parking space can now be seen in considerable detail (compare this with Figure 9).

This marked the availability of considerably improved quality of data on a commercial basis. For example, over the past three decades, the capabilities of the civil remote sensing satellites have increased some 130 times with the current best resolution of 0.61m. Not only this but, it is now possible to purchase images acquired by various countries.

Inability of optical devices to penetrate clouds and darkness can be overcome by the use of a radar sensor that not only can see through cloud cover and darkness but they can also penetrate camouflage. Vessels as small as 20m long have been observed on the sea surface by civil radar satellites. Soviet radar satellites, Almaz, are reported to have a resolution about 15m.[3] Imageries from Almaz are available commercially. Other countries that have launched radar satellites are Canada (Radarsat-1, 25m coarse mode and 9m fine mode), Europe (ERS-2, 26m, Envisat-1, 27m) and Japan (Alos 7m, and IGS-2).

5 Some Conclusions

From the above brief orbital analysis it is clear that orbits of observation satellites are designed to cover the surface of the Earth completely. For example, with on orbital period of just under 90 minutes, the ground tracks are slightly displaced every 16th orbit.[4] Moreover, in order to increase the frequency of observations of a particular target on the Earth, several satellites have to be deployed. However, orbiting them in a single orbital plane staggered from each other (see Figure 7) is not a very effective method. It was shown that it is more

[3] Radar remote sensing satellite, Radar data published in Buyer's Guide by Space Commerce Corporation in the USA.

[4] The Earth rotates on its axis by 360° in 24 hours (1440 minutes). Thus, in 90 minutes (the orbital period of a satellite) it will rotate by (90 x 360)/1440 or by 22.5°. Therefore, with the period of 90 minutes, the satellite will return to its original position after 360/22.5 or 16 orbits.

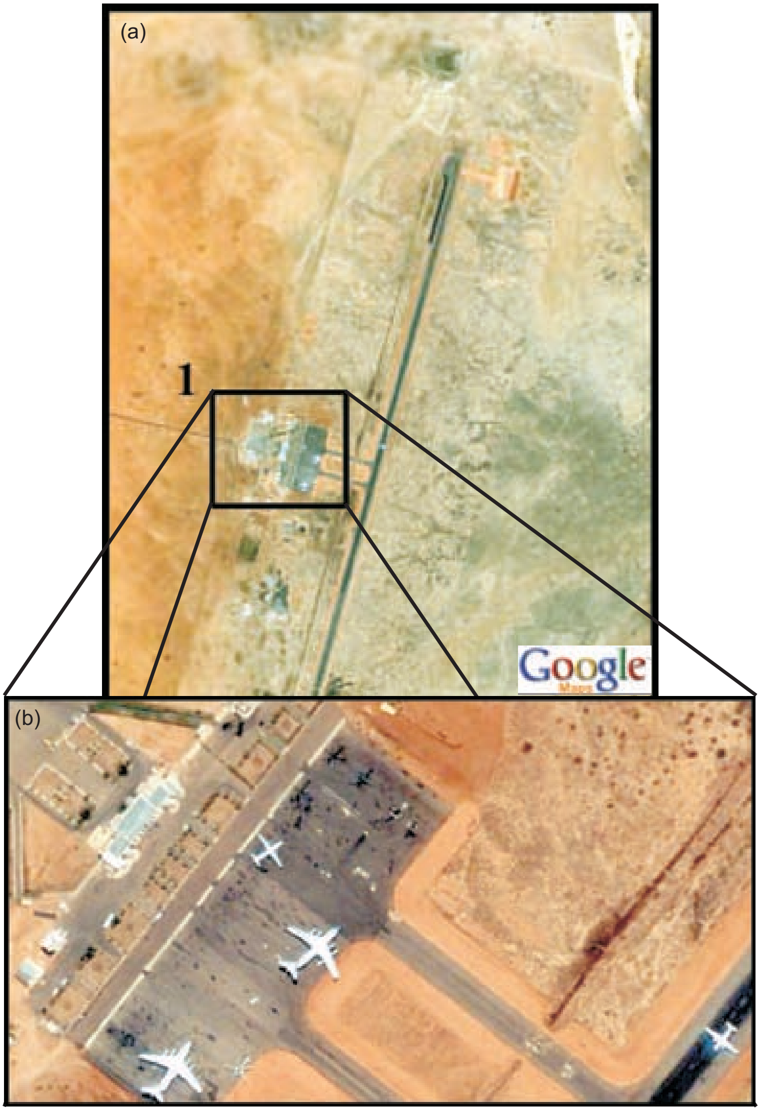

Fig. 10. *A military airfield situated to the East of Nyala in Sudan was photographed by the US QuickBird-2 satellite. Image (a) is an overview of the airfield; and (b) is the enlarged section of the inset. In such images the aircraft can be described and in this image the helicopter propellers can be seen very clearly.*
Source: Google Earth sites: http://earth.google.com

useful to orbit a number of satellites each in an orbital plane that is separated by a specific RAAN but maintaining the orbital inclinations the same (similar to that depicted by Indian satellites in Figure 8). Furthermore, with satellites placed at different AoPs, and with their tilting capabilities, much improved coverage could be achieved. However, this requires considerable cooperation between the operators of different satellites. Failing this, the burden may fall on a single country or an organization. In fact the establishment of an international agency that could do this was suggested as long ago as 1973 [9] and then again by France in 1978 [10]. Subsequently a regional concept was proposed [11] that was realized in 1991 when the Western European Satellite Centre was realized. This is now known as the European Satellite Centre.

There is no doubt that during the past four years or so, perception of national and international security has changed. Notion of threats from states is now extended to threats from non-state organisations. For example terrorism and unauthorised transaction in nuclear materials are assuming a great significance. Also conflicts within states make up for more than 95% of armed conflicts. Some of the most important elements of security are arms control treaties, disengagement and peace agreements and confidence building measures. While there is some way to go, Europe and other countries are beginning to acquire their own independent capabilities in the application of space assets for their own security. Could this not be carried out jointly in cooperation?

References

[1] Jasani B, Lee D (1984) Countdown to Space War. Stockholm International Peace Research Institute. Taylor and Francis, London: 16-17

[2] Jasani B (1982) Some Basic Orbital Concepts. In: Jasani B (ed) Outer Space: A New Dimension of the Arms Race. Stockholm International Peace Research Institute. Taylor and Francis, London: 8

[3] Jensen J, Townsend G, Kraft D (1962) Design Guide to Orbital Flights. McGrew-Hill Book Co Inc, New York Toronto London: 785

[4] http://www.satscape.co.uk/

[5] Jasani B (1991) Outer Space as a Source of Conflict: An Overview, In: Jasani B (ed) Outer Space: A Source of Conflict or Co-operation. United Nations University Press, Tokyo: 25–26

[6] How satellites may help to sell SALT – SALT II special report. U.S. News & World Report 15, 21 May 1979: 25

[7] The White House (1995) Release of imagery acquired by space-based national intelligence reconnaissance systems, executive order 12951. Washington D.C, 24 February 1995

[8] Ali FI (2001) Spy in the Sky? The Week, 4 November 2001

[9] Jasani B (1973) Verification using reconnaissance satellites. SIPRI Yearbook 1973. Almqvist & Wiksell, Stockholm: 60–101

[10] UN document A/S-10/AC 1/7, 1 June 1978

[11] Jasani B (1983) A regional satellite monitoring agency. Environ Conserv 10(3): 255–256

http://www.springer.com/978-3-540-79131-7

International Safeguards and Satellite Imagery
Key Features of the Nuclear Fuel Cycle and
Computer-Based Analysis
Jasani, B.; Niemeyer, I.; Nussbaum, S.; Richter, B.; Stein,
G. (Eds.)
2009, VIII, 176 p., Hardcover
ISBN: 978-3-540-79131-7