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ABSTRACT

Science and technology have long provided human kind with tools to discover and master the Nature. There is a revolution in observation and measurement systems, without which there can be no progress in science or technology, nor any effective long-term action. The input from satellite observation has been considerable. Space offers us a unified view of the planet with Earth observation satellites playing a major role. To go beyond observation and local studies, to set up our policies and demands, detailed knowledge of the extent of any phenomena, their cycles and trends, should be stated. The size and remoteness of the areas involved make satellite imagery an essential component of a coherent approach.

The need of up-to-date maps nowadays becomes a necessity. The rapid changes in the content of topographic maps as well as the continuous change in the user requirement push mapping agencies in the direction of the development of production methods. In conformity with this current trends, the present research may be interesting to those who are involved in measuring, studying or managing earth resources. It is directed primarily to the practical use of the space imagery, not to theoretical mathematics or electronics investigations. Among the spaceborne platforms currently being operated, the French Satellite Probatoire pour L'observation de la Terre, Abbreviated as SPOT, is chosen to be the main subject of this paper. The stereoscopic capability of the SPOT imagery is the prime motivation behind this choice.

Because of the tremendously rapid advancement that has happened since the launch of SPOT-1 in 1986, and the great competition that has arisen among researchers since then, it seems there was no enough time to collect the basic definitions, the theories and the practical tests, applications and experience connected with the SPOT system, and put them in comprehensive literature. Hence, the presentation of a more insight investigation into the subject becomes a necessity. So, the main aim of the present paper is to present a well assembled material about the SPOT system, including the previous researches and experience, to which many users can refer and achieve remarkable benefits associated with the subject matter.

1. INTRODUCTION

Science and technology have long provided human kind with tools to discover and master the Nature, especially in the trend of measuring, studying and managing earth resources. In this respect, the input from artificial satellite observation has been considerable and effective. The size and remoteness of the areas involved make satellite imagery an essential component of a coherent approach. The rapid changes in the content of topographic maps as well as the continuous change in the user requirement push mapping agencies in the direction of the development of production methods. Among the spaceborne platforms currently being operated is the French Satellite Probatoire pour L'observation de la Terre, Abbreviated as SPOT. Such SPOT system can be considered one of the important space systems, particularly for its recent mapping capabilities, and hence, represents the main point of our interest here.

Because of the tremendously rapid advancement that has happened since the launch of SPOT-1 in 1986, and the great competition that has arisen among researchers since then, it seems there was no enough time to collect the basic definitions, the theories and the practical tests, applications and experience connected with the SPOT system, and put them in comprehensive literature. This has been actually the basic motivation behind the current presentation.

In early 1978 the French Government decided to undertake the development of the System Pour l'Observation de la Terre or SPOT program. Shortly thereafter, Sweden and Belgium agreed to participate in the program with the aim of launching the first of a series of SPOT earth observation satellites. Conceived and designed by the French Centre National d'Études Spatials (CNES), SPOT has developed into a large scale international program with ground receiving stations and data distribution outlets located in many countries allover the world [Lillesand and Kiefer, 1987].

The first satellite in the program, SPOT-1, was launched from the Kourou Launch Range in French Guiana on February 21, 1986. This satellite began a new era in space remote sensing, for it is the first earth resources satellite system to include a linear array sensor and employ push-broom scanning techniques. It is also the first system to have pointable optics. This enables side-to-side off-nadir viewing capabilities, and it provides full-scene stereoscopic coverage of the same area. Like its Landsat counterpart series, the SPOT program has been designed to provide long-term continuity of data through the anticipated launch of several SPOT systems. The launch of SPOT-2 took place on January 22, 1990 [Moskwa, 1990].

The launch of SPOT-3 took place in September 1993, commissioned on November 26, 1993 [Brachet, 1994]. A number of design changes are proposed for SPOT-3 and SPOT-4. These changes include the addition of a 20 m resolution band in the mid-infrared portion of the spectrum between 1.58 and 1.75 μm. This band is intended to improve vegetation monitoring capabilities of the data. Furthermore, mixed 20 and 10 m data sets will be co-registered onboard instead of during ground processing. Another proposal for SPOT-3 and SPOT-4 is the inclusion of a new wide field of view instrument, to be flown in combination with the HRVs, which increases the view width to about 2200 km on the earth surface. This instrument records 10-bits data in five spectral bands which are: the three HRVs bands currently in use, the mid-IR band described above, and a blue band (0.43 to 0.47 μm) designed for oceanographic studies [Lillesand and Kiefer, 1987].

SPOT-4 is planned to be launched in 1997. In addition, SPOT-5 and SPOT-6, will be ready in 1999, while their launch is planned to be in 2002 and 2005, respectively [Brachet, 1994]. For SPOT-5 satellite, an improvement in the ground resolution will be achieved (5 meter on ground), by increasing the number of CCDs to be 12000 detectors in the (P) mode. Also, its life time is increased to be 5 years. Moreover, SPOT-5 will provide a new function, which is in-track stereoscopy (3 HRVs instruments, Fore, Nadir and After) with a viewing angle ±19.2°. This is besides the normal off-track stereoscopy.

On the other hand, further improvements in SPOT-6 have not been issued yet [Sujanani, 1995].

The SPOT system comprises the following main components: an orbiting satellite with two High Resolution Visible (HRV) instruments, ground facilities for image reception, preprocessing, distribution, satellite monitoring, and preparation of imaging programs [CNES, 1989a].

The main objective of the present paper is to give a thorough, but concise, insight investigation into the main concepts and capabilities of the SPOT system. In this context, a well-assembled material about the SPOT system will be given, including the previous researches and experience, to which many users can refer and achieve remarkable benefits associated with the subject matter. The stereoscopic facilities, and hence, mapping capabilities, of the SPOT system will be of special concern in the present paper. Our discussions herein will be directed primarily to the practical use of the space imagery, not to theoretical mathematics or electronic investigations.

2. The SPOT Satellite

The primary purpose of a SPOT satellite is to acquire earth imagery and to transmit the corresponding image data either in Direct mode or Recording mode to ground receiving stations. The satellite comprises two parts (Fig. 1) namely: payload and SPOT multimission bus. Each payload for SPOT-1, SPOT-2 and SPOT-3 satellites consists of two identical High Resolution Visible (HRV) imaging instruments, magnetic tape recorders, and a payload telemetry subsystem for data transmission to ground stations. The SPOT bus is designed to perform all housekeeping functions necessary for the successful accomplishment of the mission. These functions include: orbit control, three axes stabilization, power supply, thermal control, housekeeping telemetry, command uplinking, and payload programming by an onboard computer, whose memory is loaded by remote control at regular intervals. The geometry of the SPOT orbit will be illustrated first. Then the main physical characteristics of the SPOT satellite, as well as the basic functions of the SPOT satellite will be presented.

2.1 SPOT Orbit

The fundamental requirement of a remote sensing satellite is to allow comparison of images acquired on different dates. The orbit of such satellites must therefore provide certain special characteristics with respect to regularity and synchronism. These characteristics are derived, on the one hand, from calculations concerning the oblate shape of the earth (e.g. that modifies the theoretical orbit around a supposedly spherical earth), and on the other hand, from continuous monitoring of the satellite's orbital parameters. Once these have been determined, the time at which the satellite passes above a given zone can be computed and a simple universal pass schedule established. There are two main orbit characteristics which must be noted:

First, the basic requirement is that all images provide the same characteristics irrespective of the point observed. This implies a circular orbit, in other words, an orbit at a constant altitude above the earth's surface. In practice, however, and even with a near-circular orbit, the altitude of the satellite at the equator and poles is slightly different (Fig. 2) due to the oblate shape of the earth. The radius of the earth at the equator is 21.4 km longer than it is at the poles [Nassar, 1989].

Second, the satellite must be able to image any area on the earth's surface, which requires a near-polar orbit. In fact, the earth rotates about its own axis inside this orbit with the subsatellite point describing tracks at regular intervals on the earth's surface. A working cycle, or imaging cycle, must be created, so that the satellite can regularly pass over any point on the ground. At the end of certain time interval, the satellite must have completed integer number of revolutions in its orbit and the earth has completed an integer number of revolutions about its own axis. The satellite and the earth will then have returned to

their original positions with respect to each other. In these conditions, the satellite orbit is said to be phased with respect to the earth.

The SPOT satellite has been designed to circle the earth 14 and 5/26 times each day at an altitude of 830 km (at the equator). After 26 days (i.e. 26 rotations of the earth) the SPOT satellite completes a whole integer number of revolutions(369). It then begins a new 26 day cycle in which the satellite follows exactly the same ground tracks as before. The angle between the sun and the orbital plane therefore remains constant throughout the year. Node line rotation in fact results from a perturbation with respect to Kepler's laws [Nassar and Abu-Beih, 1987], mostly attributable to the equatorial swell, or the oblate shape of the earth. The inclination of the orbital plane about the equator is carefully chosen to account for this perturbation and to insure that the rotation of the node line is synchronous with that of the sun (in its apparent movement around the earth). For a circular orbit at an altitude of 830 km, sun synchronism is obtained for an inclination of 98.7°.

The theoretical characteristics of the SPOT satellite orbit described above are nevertheless subject to certain disturbances resulted from the following effects [Nassar, 1991]: gravitation perturbations (especially the force of attraction of the moon and the sun), solar radiation pressure, and atmospheric drag. Atmospheric drag leads to a daily decrease in orbit altitude of one or more meters (depending on the level of solar activity). Hence, orbital parameters must therefore be continually monitored in order to check any drift from nominal selected values. This is the role of the Attitude and Orbit Control System (AOCS) which can perform two types of orbit correction maneuvers:

i. Corrections to increase altitude (of approximately 50 to 200 m according to the solar activity level) implemented 5 to 10 times a year, and

ii. A procedure to correct the inclination, implemented once a year.
These corrections assure that local pass times remain within 15 minutes of their nominal values and that the satellite will always pass over a given track with an accuracy of 5 km [CNES, 1989a].

2.2 Satellite Characteristics

In order to meet the SPOT mission objectives, the following basic characteristics of the SPOT satellite have been adopted:

❶ Total mass of the satellite = 1750 kg (at start of life).

❷ Overall satellite bus dimensions = 2 x 2 x 3.5 m.

❸ Total span of solar array = 15.60 m.

❹ Mass of each HRV = 250 kg.

❺ Overall length of each HRV instrument = 2.5 m.

❻ HRV instrument field of view = 4.13° (P & XS).

❼ HRV numerical aperture = f/3.3 focal length (f) of 1.082 m.

❽ HRV magnification = about 1: 770.000 for vertical viewing in mode (P), which means that, the ratio between the ground sampling interval and the physical size of single CCD detector is 770.000.

❾ Strip width in vertical viewing= 60 km. In twin-vertical configuration, the total swath width is 117 km with 3 km sidelap between the imaging strips recorded by the two instruments (Fig. 3).

❿ Strip width in oblique viewing = 60 to 81 km. Areas observed are located within a 950 km width (observable corridor) centered on the satellite ground track (Fig. 4).

❶❶ Spectral bands are in two modes:

i. Panchromatic mode (P): imaging in a single spectral band (visible) extending from 0.51 to 0.73 μm.

ii. Multispectral mode (XS): imaging in three wavelength bands; green (0.5-0.59 μm); red (0.61-0.68 μm); near infrared (0.79-0.89 μm).

❶❷ Line sampling interval in vertical viewing = 10 m in case of spectral mode P and 20 m in case of spectral mode XS.

3. SPOT Imagery and Data Products

SPOT images take the form of high resolution color or black and white images composed of a set of points known as pixels. Each image is formed by scanning successive lines and by analyzing the light returned by each ground patch area. The point on the ground corresponding to a particular pixel on the image is called the ground patch area.

In a given spectral mode, the HRV instrument images a single line of the landscape at a given moment. All the points making up one line are analyzed simultaneously. The motion of the orbiting satellite (and the corresponding shift of the imaged line) allows acquisition of a complete image (Fig. 5). The distance between two contiguous pixels on the same scanline is called the line sampling interval. Similarly, the distance between two contiguous pixels in the same column is called the column sampling interval. The line sampling interval reflects the space separating each individual Charge Coupled Device (CCD) detector in the HRV instrument.

The column sampling interval is derived from the time interval between acquisition of two successive lines. This time interval, known as the line period (time required to electronically scan a complete row of detectors), is a fundamental characteristic of the SPOT system. The line period is equal to 1.504 millisecond, for panchromatic mode and 3.008 millisecond, for multispectral mode [CNES, 1989a]. The column (or row) sampling interval is therefore equal to the distance by which the imaged line is displayed during one line period. For such given data, for the SPOT system, one can find that, for vertical viewing, the sampling interval will be 10 m in panchromatic mode and 20 m in multispectral mode [CNES, 1989a]. In the following two subsections, the SPOT image analysis will be outlined in general words; and the SPOT scene will be specifically given, as far as both dimensions and viewing orientation are concerned.

3.1 Image Analysis and Processing

Image analysis of measuring the radiation (visible or near-infrared) reflected by the imaged object, in one or several spectral bands, can be performed either in black and white or in color. Black and white analysis (panchromatic spectral mode) is carried out in the visible spectrum band, i.e. 0.51 μm to 0.73 μm (Fig. 6). The panchromatic mode is intended primarily for applications requiring fine geometric details.

Color or multispectral mode analysis utilizes three spectral bands (Fig. 6): green (0.5-0.59 μm), red (0.61-0.68 μm), and near-infrared (0.79-0.89 μm). These three bands together assure improved spectral response to chlorophyll and specifically to a response peak in the green band, strong absorption in the red band, and pronounced response in the near-infrared band, which cannot be perceived by the human eye.

When images are recorded on photographic film, the signals recorded in these three wavebands are converted to the visible spectrum resulting in what is known as false color image. This explains why on the most commonly used color recordings, vegetation appears as red (as in photographs taken using color-infrared film). False color recordings should not be confused with pseudo-color images that are artificially colored black and white images.

3.2 SPOT Scene Geometry

By scene geometry, one means the description of both scene dimensions and viewing orientation. As SPOT satellite orbits the earth, each HRV instrument produces a continuous strip of images from 60 to 81 km wide which is split into 60 km long scenes. A raw scene acquired in panchromatic mode comprises 6000 x 6000 pixels, and when acquired in multispectral mode, it comprises 3000 x 3000 pixels. Figures' 7a&b show the SPOT image geometry. Scene dimensions and image orientation elements in these two figures are defined as follows [CNES, 1989a]:

C_o = scene center.
C_1, C_2, C_3, C_4 = scene corners.
l_1 = distance on the image from C_o to the left edge of the scene.
l_2 = distance on the image from C_o to the right edge of the scene.
γ = image orientation angle.
a = angle between the perpendicular to the image lines and the left hand edge of the image (earth rotation).
α = angle of incidence.
D = distance between the satellite and the scene center C_o.
θ = HRV instrument field of view (4.13°)
R_l = local earth radius.

The boundaries of the ground zone corresponding to a scene vary according to the latitudes (Φ) and the viewing angle (β). In geometric terms, a SPOT scene is defined by its four corners C_1, C_2, C_3, and C_4 and the scene center C_o. In practice, the width (sides C_1C_2 or C_3C_4) varies from approximately 60 to 81 km, whereas the length (sides C_1C_3 or C_2C_4) remains constant at 60 km. The scene center C_o (pixel NO. 1501 in XS mode and 3001 in P mode) is not located at the middle of the center line, due to the panoramic effect and the curvature of the earth [CNES, 1989a]. This is why a distinction is made between lengths' l_1 and l_2 on each side of scene center C_o.

The image line acquired at a given moment by the HRV instrument is approximately 7.5 km in front of the subsatellite point in panchromatic mode and 7.5 km behind the subsatellite point in multispectral mode (Fig. 8). Each HRV instrument can execute both vertical and oblique viewings. The subsatellite point is defined by the intersection of the earth's surface and the geometric vector having its origin at the satellite and perpendicular to the earth's surface.

An HRV instrument is said to execute vertical viewing when the viewing angle (β) is between -7.5° and +7.5° (Fig. 9). An HRV instrument is said to carry out oblique viewing when the absolute value of the viewing angle (β) is greater than 7.5°. Viewing angles are defined in 0.6° steps within the range ±27° (Fig. 10). The desired viewing angle is selected for each instrument by rotating a mirror, called the Strip Selection Mirror (SSM), at the entrance of the HRV telescope.

3.3 SPOT Data Products

SPOT data are available at several different preprocessing levels, and include image data and the corresponding SPOT auxiliary data. SPOT IMAGE Company offers a large choice of formats and media to adapt products to user's needs. SPOT scenes can be supplied on many media such as Computer Compatible Tapes (CCTs), CD-ROM optical media and photographic media (either in film or paper prints). The evaluation and final use of SPOT images therefore depend on the knowledge of preprocessing and processing operations applied to them. Consequently, SPOT scene does not become a product until it has undergone some preprocessing operations. In this context, there are seven such

preprocessing levels, which are applied in both panchromatic and multispectral modes, namely: 1A, 1AP, 1B, 2A, 2B, S1, S2 levels, respectively [CNES, 1989b and CNES, 1990].

Level 1A is a raw image data level where detector normalization only is performed in each spectral band. This level is normally selected by users wishing to obtain information that has undergone the least possible processing. Level 1AP panchromatic and multispectral products are specifically optimized for photogrammetric applications using analytical stereoplotters. When analyzed using a digital analytical stereoplotter, this level product improves quality of interpretation and provides a higher geometric accuracy and greater operator comfort. Level 1B is the basic preprocessing level, which includes radiometric and geometric corrections (viewing characteristics). Level 2A is a precise preprocessing level in which the geometry of the image and location accuracy are improved. Besides the radiometric and unidirectional correction applied at level 1B, a second type of geometric correction is performed to the image which is called bidirectional correction. Geometric corrections in cartographic projection are done without using ground control points (GCPs). Level 2B is the same as level 2A, except that the geometric corrections are done using GCPs. Level S1 is a precise level that produces scenes that can be registered pixel to pixel with a reference image. The reference image is preprocessed to level 1B. Level S2 is the same as level S1, except that the reference image is preprocessed to level 2B. Table 1 summarizes the basic differences among these seven preprocessing levels with respect to the following items: medium and description [CNES, 1993].

There are three types of auxiliary data, namely: image acquisition information, scene geometry and scene radiometry, whose main constituents are listed as follows:

i. Image acquisition informations include; satellite No., instrument No., spectral band No., SGRS designators, viewing date and time, angle of incidence, image orientation angle, geographical coordinates of the four scene corners, difference in latitude and longitude between the scene center and the nearest SGRS node and sun angles (Azimuth and elevations).

ii. Scene geometry comprises: line and column designators, geographic marks, attitude and look angles for the beginning and end of the scanline (available with soft copy products only).

iii. Scene radiometry (available with soft copy products only) consists of: gains applied to each spectral band, list of current dark values, list of CCD normalization coefficients, histogram of radiometric values and dynamic range stretching method used.

3.4 The Main Differences Between SPOT Imagery and Aerial Photography

The main differences between SPOT imagery and aerial photography will be treated here, from the stereoscopic view point. SPOT stereopairs differ in some ways from pairs obtained by aerial photography. Such differences can be drawn from previous experience gained during the SPOT satellite operations [CNES, 1989b] through the stereoscopic photogrammetric implementation. The main differences between the two systems can be summarized concerning the following items: mean scale of photographic products, viewing dates, preprocessing levels, image orientation and vignetting, and will be given as follows:

A- Mean Scale of Photographic Products

SPOT image cover zones much larger than aerial photographs. This feature is the most commonly cited advantage of SPOT scenes in terms of both cost and interpretation.

Conversely, existing photogrammetric equipment are not always ideal in terms of available magnifying power and the adjustments available on the film carrier size to suit

SPOT photographic products. According to this fact, in order to use the SPOT photographic products in the photogrammetric equipments, the scale of SPOT products should be ranging between 1:400.000 and 1:266.000.

B- Viewing Dates

The fact that the two SPOT images in the stereopair are obtained at an interval of several days or weeks implies the following consequences, which may be considered as a disadvantage of using SPOT photographic stereopair, that is:

i. Vegetation cover may vary, thereby impeding stereoscopic vision.

ii. The variation of solar angle leads to different shading effects, however, this is not really a problem, it can be used as an advantage for stereoradiometric studies.

iii. If one of the SPOT images includes some cloud cover, cloud shadow makes stereoscopic observation of the target zones more difficult.

C- Preprocessing Level

As a rule, stereoscopic applications can use images preprocessed to any level, which is an advantage of the SPOT products.

D- Image Orientation

SPOT image orientation depends on latitude (Φ) and viewing angle (β). For example, for a B/H ratio of unity, the difference in orientation will be 0° at the equator and up to 8° for areas situated at 45° latitude. However, in aerial stereopairs the orientation angles are different, for instance, they are defined by the well known angles ω, Φ and κ. Consequently, allowance must be made for such difference in orientation between SPOT and photogrammetric stereopairs, when arranging the two SPOT images for use in photogrammetric instruments.

E- Vignetting

SPOT images are not prone to the vignetting effect encountered in aerial photography, since the useful field of the HRV instrument is smaller than that of aerial cameras.

Section 6 will summarize, with some more details, the previous experiences gained with the practical applications of SPOT imagery in mapping. Some emphasis will be oriented towards the obtainable accuracy, in both planimetry and heights, as compared with the corresponding photogrammetric processes. In addition, SPOT imagery treated to different levels will be indirectly included within the particular samplified previous investigations.

4. SPOT Reference Coordinate Systems

There are two types of reference coordinate systems associated with the SPOT system, namely: Geodetic Reference System (GRS) and SPOT Grid Reference System (SGRS). Since the SPOT satellite orbits the earth, and controlled by its gravitational field, its position at any instant, (e.g. the epoch of taking any image), should be described in three dimensional coordinate frame, fixed within the earth body. Such a frame, should have a global or worldwide nature, and hence is referred to as a Geodetic Reference System (GRS). The most recent GRS which has been adopted internationally is the one of 1980, and named GRS 80 [Nassar, 1991]. On the other hand, since the SPOT satellite takes images for different scenes, covering the whole earth surface, it was found necessary to adopt another reference coordinate system, which defines the location of each scene on the earth surface. Such a system, known as the SPOT Grid Reference System (SGRS), is

composed of nodes defined by row and column intersections of a certain grid covering the whole surface. Each row and column are expressed according to a specified numbering system. Both the GRS 80, as well as the SGRS, will be explained in the following two subsections.

4.1 Geodetic Reference System (GRS 80)

The earth, represented by its topographic surface (mountains and oceans), can't be expressed by a mathematical surface. However, it can be represented by the most important equipotential surface of the earth's actual gravity field, which is the geoid surface. Such a surface is quite irregular, located near the mean sea level and extends underneath the continents forming a closed surface. Hence, it is tedious to use it as a mathematical surface for the earth, besides it is not symmetric around the equatorial plane. On the other hand, if we accept a model of the geoid which is accurate to within one hundred meters, we could describe it as an ellipsoid [Nassar, 1989].

There are, in fact, a number of ellipsoids, each of which is adapted to the description of a particular part of the geoid. The ellipsoid which best describes the geoid as a whole is the 1980 Geodetic Reference System (GRS 80), which has been adopted at the 17th General Assembly of International Association of Geodesy and Geophysics (I.U.G.G) in December, 1979 [Moritz, 1984]. Its size and shape defining parameters are as follows (Fig. 11):

Semi major axis= R_a= 6378.137 km.
Semi minor axis= R_b= 6356.752 km.

The GRS 80 takes the form of a normal right-handed set of orthogonal axes fixed with respect to the earth and defined as follows (Fig. 11):

i. The origin of this set of axes lies at the center of the earth's mass (O).

ii. The OX axis lies in the meridian zero (Greenwich Mean Astronomic Meridian) and the equatorial plane of the ellipsoid.

iii. The OZ axis coincides with the revolution axis of the Reference Ellipsoid (Mean Rotation axes of the earth).

iv. The OY axis is perpendicular to the XZ plane thus forming a right-handed set of orthogonal axes (OXYZ).

4.2 SPOT Grid Reference System (SGRS)

The SPOT Grid Reference System, or SGRS, is a means of identifying the geographic location of SPOT images. The grid is made up of nodes located at the intersection of columns (K) and rows (J). The SGRS indicates the nominal location of scenes (in terms of row and column numbering of intersection nodes) that can be acquired in the twin vertical viewing configuration, taken by the two HRV telescopes, for any region in the world except polar zones. In the case of oblique viewing, the scene centers do not normally coincide with the SGRS nodes. SPOT scenes acquired in oblique viewing mode are identified by the (K,J) designators of the node closest to the scene center.

The SGRS divides the earth into five zones forming a symmetrical pattern on either side of the equator (Fig. 12). This division is dictated by the satellite's orbital characteristics and more specifically by the convergence of the ground tracks at high latitudes. The SGRS five zones are defined as follows:

i. The Intermediate Zone extends from 51.55° N to 51.55° S in latitude.
ii. The North and South Zones extend from 51.55° to 71.7° north and south respectively.

iii. The North and South Polar Zones for latitude beyond 71.7° north and south respectively.

Extracts of the SGRS for the five zones mentioned above have been published for almost all land masses. They form a set of 16 sheets whose layout is shown in figure 13.

The K columns are derived directly from the SPOT reference tracks. Each track number N corresponds to two K columns:

i. K= 2N-1 (odd number) associated with instruments HRV1 and located to the west of track N.

ii. K= 2N (even number) associated with HRV2 and located to the east of track N.

The distance between these two columns (i.e. between K= 2N-1 and K= 2N) is constant at about 58 km and is a direct result of twin-vertical configuration (Fig. 14). The SGRS is, hence, different from the Landsat grid reference system (WRS), where the nodes are located on the tracks and not on either side.

J rows correspond to latitude lines, i.e. all SGRS nodes located on the same latitude line share the same J designator. The interval between the rows has been calculated to ensure that there is always a minimum overlap between two successive scenes (Fig. 14).

In the intermediate zone, the SGRS comprises 738 K columns numbered from 1 to 738 to the east, and 209 J rows numbered from 246 to 455 from north to south, resulting in 154242 nodes. However, for Egypt, which lies in this zone, comprises 31 K columns numbered from 98 to 128 eastwards, and 21 J rows numbered from 286 to 306 southwards, resulting in about 450 nodes on the earth masses within the Egyptian territory (Fig. 15).

In view of the progressively closer packing of the reference tracks as latitude increases, only 2K columns out of 4 are maintained in the North and South zones. Thus, only 370 columns corresponding to odd-numbered reference tracks N are used with 46 J rows numbered from 200 to 245 and from 455 to 500 from north to south, resulting in 17020 nodes.

For the North and South Polar Zones, the SGRS numbering system follows certain special arrangements among meridians and parallels of latitude, i.e. tracks and lines of latitude, or columns and rows, such that each polar zone comprises 22591 nodes.

5. SPOT Stereopair Acquisition, Selection and Applications

The oblique viewing capacity of an HRV instrument, by means of the Strip Selection Mirror (SSM), can be used to acquire stereopairs (Fig. 16a&b). Figure 16a illustrates the frequent acquisition opportunities during a given cycle. Figure 16b shows the stereoscopic viewing resulted from parallax created by the two oblique viewing angles. A stereopair comprises two separate images acquired at least one day apart on different passes over the target areas either by the same or a different HRV instrument. This means that relief perception by means of stereopairs obviously does not depend on the fact that the payload comprises two identical instruments.

The following four main factors must be taken into consideration during the stage of selecting SPOT stereopairs, which are:

i. The B/H ratio, which depends on the value of the angle of incidence (α) (Fig. 7a&b).

ii. The difference between the viewing dates, which can be calculated by comparing scene viewing dates (Year, Month, Day in UT).

iii. The cloud cover, whose notation is included in the SPOT products auxiliary data, as given in section 3.3.

iv. The degree of overlap, which can be judged by the geographic coordinates of the four corners of each scene.

The way in which these four criteria are applied depends on whether the scenes are selected from existing SPOT images (Catalog Consultation) or specifically acquired in answer to a Programming Request. When searching for SPOT Image Catalog in Toulouse Center (France), for existing scenes to form a stereopair, the user can refer to the auxiliary data, as mentioned in section 3.3, for a given pair to determine whether it meets these four criteria or not. If a suitable stereopair is unavailable in the SPOT Image Catalog, or if wider stereo coverage is required, users can submit special Programming Request. Also, a stereopair can be created by selecting an existing image and submitting a special Programming Request for acquisition of the second image.

Stereoscopic applications can be divided into two main categories which differ in terms of the accuracy required and therefore the types of equipment used. The first category is photointerpretation, which incorporates relief perception, and uses a variety of instruments, ranging from a simple pocket stereoscope to the largest mirror-type stereoscope. The second category is photogrammetry, which involves accuracy to a fraction of a pixel, and which uses analytical stereoplotters and possibly data processing techniques to create digital terrain models automatically.

6. Previous Experience with SPOT Imagery

Presented in this section is a concise review of the previous experience concerned with the SPOT photogrammetric field gained in both the theory and the practice. Broadly speaking, there are two specific fields into which most of the researchers investigate. The first field, which has just been referred to as "photogrammetric", has the "metric data" as its eventual goal. Again, within this same field, some researchers focus on deducing mathematical models that serve processing of SPOT data. The other trend of researchers in that first field incline to implement the theories to special applications in practice and to hold accuracy studies and/or comparative studies. The second field of researchers deals mainly with semantic data as its main aim. That is, the focus is on the nature of objects and their identification [Thirlwall, 1988; Labuda, 1988].

The first of the following two subsections presents a very brief summary of the various geometric approaches of the established mathematical solutions. No listing of equations is given. The second subsection summarizes the valuable practical conclusions and achievements reported by the researchers. In both subsections, a numerous number of cited references will be carefully listed within the text, at all appropriate locations. This has been meant for the convenience of the reader, to look for any further details connected with the subject matter.

6.1 Theoretical Considerations and Mathematical Treatment

The CCD line scanner geometry can be respected with various mathematical models. They can generally be classified into two main categories. The first, which is sometimes referred to as the non-photogrammetric approach [Kratky, 1988], models indirectly the individual or combined effect of physical reality of imaging, satellite orbiting and earth shape by empirical image fitting and warping [Guathier, 1988]. In the second category, the physical reality and the dynamic situation typical of SPOT is fully respected.

Rodriguez et al [1987], deduced approximate formulation of the viewing system. It depends on the determination of the two correspondences: the position of the viewing point corresponding to a certain line and the look direction corresponding to a certain pixel in that line. These correspondences are determined from approximated correspondences (satellite ephemeris and attitude data), stereoplotted measurements of ground control points and homologous points.

Sharpe [1988] applied geometric corrections in a two stage process. In the first stage, correspondence between any given pixel in the input imagery and a point on the earth's surface is established. The correction process in this stage uses four models, namely the sensor model, the earth model, the orbit model and the attitude model. Before shifting to the second stage, precision models are determined by refining the systematic orbit and attitude models by incorporating ground information about ground control points. The second stage is the resampling of the input imagery to points on the desired output grid. Great care has been taken in Meridian to develop resampling kernels that preserve radiometric fidelity using a three-pass one-dimensional resampling technique [Friedmann, 1981].

Kruck [1988] admitted a straight-line track with irregular effects which are assumed to be variations of the angles ω, Φ and κ. The angle variations are taken into account using additional parameters. The additional parameters are included in the BINGO bundle adjustment software. The measured image coordinates are also corrected before inputting them to the program. The corrections account for known minor distortions of a scene.

Shifting to the second category of geometric solutions, which is described as rigorous or sometimes universal, a number of mathematical models are mentioned here. Konecny et al [1987], with the view of producing DEM, orthophotos and line maps, deduced a rigorous method. The well known BINGO software of the bundle block adjustment is modified to handle CCD line scanner geometry. The orientation parameters of each scan line including the angular ones are considered to be invariant with time. Systematic errors caused by this modeling are in terms of mathematics expressed as additional parameters which change the image geometry. As in the original software, a Cartesian coordinate system located near the area of interest is used for computation.

Kratky [1988] presented a universal solution that can be implemented both in digital processing systems and in analytical photogrammetric instruments. The images are analyzed in their original raw form (level 1A) corrected for radiometry only. The geometric solution combines the principles of photogrammetric bundle formulation, modified in a time dependent mode, with additional constraints derived from known orbital relations. The constraints account for the satellite position deviations from nominal positions, angular rotation about the three axes as second degree order polynomials in time and linear and quadratic scale changes across the orbit. The solution concept was successfully expanded to process long strips of stereoimagery in a photogrammetric triangulation mode for ground extension.

Gugan and Dowman [1988a&b], used the Eulerian elliptical parameters to model the SPOT system. True anomaly and longitude of ascending node were assumed as first order degree polynomials in time to represent the earth rotation and orbit elliptical shape. Then collinearity equations were deduced and solved by least squares adjustment.

Westin [1990] assumed the satellite orbit to be in a circular plane during frame imaging period. Thus the semimajor axis of the elliptical orbit and the argument of the perigee are replaced by the assumed circular orbital radius and the time of epoch becomes the time origin at the ascending node. The ephemeris data and the attitude data measured on board are used to calculate the coefficients of cubic polynomials in time accounting for the orbital radius and the angular parameters. Collinearity equations govern the model are then solved by least squares adjustment.

El-Manadili [1994] developed a general mathematical model for simulating the platform parameters. The trajectory of the satellite is assumed to be an ellipse with certain parameters that can be determined from the adjustment. Satellite deviations are modeled using the perturbation velocity and acceleration vectors. The technique employs the sensor attitude angles to describe the satellite orientation with respect to the ground coordinate system, and the attitude variations with respect to time using the available auxiliary data like the satellite incidence angle, ephemeris data, time at frame center, satellite altitude, look angle data and sensor attitude data. The mathematical model is based primarily on the collinearity equations.

An excellent classification and analysis of the various mathematical models is presented by Mikhail and Paderes [1991]. A comparative study among the different approaches led to valuable conclusions that can be summarized in the following. Developing differences between ideal and actual parameters into polynomials is better than recovering the whole parameters themselves. Also, it is more effective to consider such differences relative to a local system of coordinates than a global one. Approximating the SPOT orbit with a circle is perfectly suitable for a stereopair providing that the differences are modeled properly and using ephemeris data. Perhaps for strips this will not be perfect. When parameterizing the orbit by either Eulerian or State Vector approaches, no difference is exhibited. Near perfect correlation among parameters, particularly added parameters must be carefully considered. The ephemeris and attitude data, whenever available, should be used particularly when little or no control is available. Lastly, when ephemeris and attitude data are not available, the orbit parameters should be updated outside the adjustment loop and the adjustment should be repeated at least once.

6.2 Practical Achievements

A definite evaluation of the SPOT potential, as far as mapping accuracy is concerned, has been achieved by almost all researchers. This unanimous conclusion is that, from the accuracy point of view, maps of scale 1:50,000 with 20 m contour interval can be produced with SPOT data [Theodossiou and Dowman, 1990; Gauthier, 1988; Jacobsen, 1988].

However, some researchers were a bit conservative in their claims, and others were more optimistic. For instance, Hartley [1987] considered the SPOT as a mapping system not to replace traditional systems but to complement them under appropriate conditions. He stated that compilation of details is incomplete [Hartley, 1987]. Holding the same meaning, Kratky [1988] used the expression "support" rather than "produce topographic maps". On the other hand, Theodossiou and Dowman [1990] added that if the image quality is very good and the ground control is sufficient, production of maps of scale 1:25,000 would also be possible. The same conclusion is confirmed by Konecny et al [1987].

A look on the accuracy values attained in various tests shows that there is more or less an agreement on the planimetric and height accuracy. The figures may differ according to numerous factors, but still there are no odd values. Table 2 lists some of such values as examples. It also lists some relevant information necessary for completeness. Gauthier [1988] on summarizing the results of a number of such experiments, reported firmly that the standard deviation in planimetry is around 6 m, and the height 4 m with B/H ratio of unity and 8 m with B/H of 0.5. However, good images with a B/H ratio near unity are not always easy to obtain.

Still talking about accuracy figures, Theodossiou and Dowman [1990] related the standard deviation in height to the average terrain slope in the scene. The relation is manifested from the following figures: with slope 10%, standard deviation is 3.75 m; with slope 30%, standard deviation is 6.78 m and with slope 45%, standard deviation is 11.75.

The conclusions and statements concerning the factors affecting the accuracy are summarized here. First, it is clear from the above accuracy figures that both the B/H ratio and the terrain slope have clear effect on the heighting accuracy. The number and proximity of ground control points have a profound effect upon the level of heighting accuracy. For instance, if ground control points are numerous and having good distribution within the test area, the accuracy attained will generally be high. Further, the base mapping accuracy plays a great role in the final accuracy, together with the image quality, the extraction process and the operator's experience. The atmospheric conditions affect the image quality where gross errors in height are expected in areas that are affected by haze. Also in cloud covered areas, it will be difficult to have a good impression of relief [Theodossiou and Dowman, 1990]. In this issue automated image correlation techniques remove some of the problems caused by manual measurement, and thus SPOT imagery develops into a useful source of data for DEMs. Neither the spectral mode (P or XS) nor the viewing incidence are seen to have any effect on the quality of plotting [Rodriguez et al, 1987].

As to ground control acquisition, the most pervading way is to extract them from existing maps of scale like 1:25,000 [Konecny et al, 1987]. Extending control from aerial triangulation is the alternative way and is used when photographs, even of very small scale, are available. Aerial triangulation needs in turn a frame of ground control points which are best determined by EDM traversing controlled by Doppler satellite measurements or GPS measurements [Hartley, 1987].

Because the coordination of ground control points is identified as being particularly sensitive, great care is required in transferring them from relatively large scale maps or photographs onto the small scale imagery. Linear junction details provide the most reliable control points. For example, roads, tracks and roofs of built up areas made of non local materials are good features to choose [Hartley, 1987].

Practically, from 6 to 10 ground control points are sufficient to establish a model [Rodriguez et al, 1987]. The same conclusion is stated but tied to hardcopy stereopair restitution [Mikhail and Paderes, 1991]. They enumerated a number of useful notes. Most of the methods of different modelings yield essentially the same results for stereopair when six or more control points are used. The optimum distribution of control is to be well distributed when projected along each of the axes, or at least along East and North directions. When few control points are used, less than six, the advantage of rigorous modeling becomes clear, in comparison with approximated models. However, the availability and quality of ephemeris and attitude data play a significant role in such a case. Using ephemeris data and attitude information and six or more control points, one obtains essentially the same results from multi-frame strips as from single-frame stereomodels [Mikhail and Paderes, 1991].

The cost is always an important element in any study. It is very important to measure the time which is required to set up a model and complete all procedures because time is related to cost [Theodossiou and Dowman, 1990]. The time of setting up a SPOT stereomodel varies from one model to another depending on the number, the quality and the distribution of control points. The average time from editing the control points up to the final control points arrangements in order to get the best possible exterior orientation results is about 5 to 6 hours. The time of resetting the SPOT model is 15 minutes. After that, the time of measuring one block of DEM of 990 points is 45 minutes [Theodossiou and Dowman, 1990]. Setting up a model only without further processes like DTM, requires 3.5 hours [Hartley, 1987].

General comments were also valuable. The cost effectiveness of mapping from space over conventional photogrammetric techniques becomes evident, in part, from the reduction in the number of ground control points required [Sharpe, 1988]. Mapping of large areas with SPOT images is more economic than with high altitude photographs [Jacobsen, 1988]. More emphasis, and hence time and cost, in field completion is required with SPOT mapping than with traditional techniques to maintain standard

mapping specifications. This is because of providing place names, classifications and gathering details hidden by clouds or vegetation [Hartley, 1987].

Another general comment which almost all researchers agree about, is that it seems only logical and more efficient to use digital systems (softcopy) rather than analytical plotters (hardcopy), since the data are already in digital form. Digital systems also permit the merging of image data with other geographic data, thus greatly enhancing the power of the SPOT system in mapping [Gauthier, 1988].

7. Summary and Conclusions

The SPOT satellite remote sensing system is elaborated on insufficient details. The basic elements of SPOT system, including SPOT orbit and the satellite characteristics, are presented. Also, SPOT imagery is discussed in details, including image acquisition conditions and scene presentation. In addition, SPOT data products, including their different pre-processing levels, as well as their hard copy and soft copy formats are illustrated. Furthermore, the main differences between SPOT imagery and aerial photography, are explained.

Then, SPOT reference coordinate systems, are outlined. Also, SPOT stereopair acquisition, selection and applications, are stated. Finally, the previous practical experience with the SPOT stereo-imagery, either for surveying or non-surveying users, is carefully evaluated. Most of these practical investigations carried out by several researchers, are collected from the appropriate literature dealing with the subject matter. Such applications have been analyzed and discussed, from map production viewpoints. This includes, for each case, the used SPOT preprocessing level of imagery, the adopted way of treatment, the type of corrections taken into account, as well as the obtained accuracy of the final produced maps.

The present investigation concluded that, from the accuracy point of view, maps of scale 1:50,000 with 20 m contour interval can be produced with SPOT data. This means that the SPOT system, being a mapping system, is not meant to replace traditional systems but to complement them under appropriate conditions. Some optimistic researchers predict that maps with scale 1:25,000 will be possible using the SPOT imagery. One important conclusion, based on several practical tests and analyses, is that there is more or less an agreement on the planimetric and height accuracy of SPOT mapping. However, the height accuracy may be affected by the average slope of the terrain, as well as the number and proximity of the ground control points within the scene.

The cost-effectiveness of mapping from SPOT over conventional photogrammetric techniques becomes evident, in part, from the reduction in the number of ground control points required, in addition to covering larger areas.

A questionnaire is recommended to be distributed to different users of medium scale maps, to inquire about the accuracy standard each branch of application requires. Such questionnaire, should also comprises some esquires about other user requirements, to make it much more practically beneficial. Pamphlets and tables are recommended to be issued showing which users can make use of such a system and to what extent. Special software can also be developed for those who require special considerations.

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Table 1 SPOT Data Products and Its Characteristics

Preprocessing level	*Medium*	*Description*
1A/1B	◆ CD-ROM ◆ CCT ◆ Standard film 241 mm x 241 mm. Scales 1:400.000 (full scene) and 1:200.000 (quarter scene) ◆ Paper print. Scales 1:100.000, 1:200.000 (full scene) ◆ Paper print. Scales 1:100.000, 1:50.000 (quarter scene)	◆ preprocessing level 1A (radiometric corrections) or 1B (radiometric and geometric corrections) ◆ **Multispectral mode (XS)** - 20 m resampling - 3 spectral bands (green, red, near infrared) ◆ Full scene of 60x60 km (up to 80 km in oblique viewing) ◆ Quarter scene of 30x30 km (up to 40 km in oblique viewing) ◆ preprocessing level 1A (radiometric corrections) or 1B (radiometric and ◆ geometric corrections) ◆ **Panchromatic mode (P)** - *10 m resampling* - *1 spectral bands (black-and-white image)* ◆ Full scene of 60x60 km (up to 80 km in oblique viewing) ◆ Quarter scene of 30x30 km (up to 40 km in oblique viewing)
	◆ Film 482 mm X 482 mm ◆ Scales 1:200.000 (full scene) and 1:100.000 (quarter scene)	◆ Full scene or quarter scene. ◆ Preprocessing level 1A (radiometric corrections) or 1B (radiometric and ◆ geometric corrections): ◆ **Multispectral mode (XS) (20 m resampling)** ◆ **Panchromatic mode (P) (10 m resampling)**
1AP	◆ Standard film 241 mm X 241 mm with auxiliary data on CCT or MS DOS 51/4" or 31/2" disckette	◆ Digital filtering to improve linear features interpretation ◆ Preprocessing level 1AP (radiometric corrections) ◆ **Multispectral mode (XS) (bicubic oversampling at 17.50 m)** ◆ **Panchromatic mode (P) (bicubic oversampling at 8.75 m)** ◆ Film preprocessed to level 1AP ordered with corresponding CCT ◆ or CD-ROM preprocessed to level 1A

Table 1 SPOT Data Products and Its Characteristics ***continued;***

Preprocessing level	*Medium*	*Description*
2A	• CD-ROM • CCT • Standard film 241 mm x 241 mm. Scales 1:400.000 (full scene) and 1:200.000 (quarter scene) • Paper print. Scales 1:100.000, 1:200.000, 1:400.000 (full scene) • Paper print. Scales 1:100.000, 1:50.000 (quarter scene)	• Full scene or quarter scene • Preprocessing level 2A (geometric corrections in cartographic projection without GCPs). Points located by their rectangular coordinates using reference map grid marks. Pixel resampling (x and y axes) in a given cartographic projection. • **Multispectral mode (XS) (20 m resampling)** • **Panchromatic mode (P) (10 m resampling)**
	• Film 482 mm X 482 mm • Scales 1:200.000 (full scene) • and 1:100.000 (quarter scene)	• Full scene or quarter scene • Preprocessing level 2A (geometric corrections in cartographic projection without GCPs). Points located by their rectangular coordinates using reference map grid marks. Pixel resampling (x and y axes) in a given cartographic projection. • **Multispectral mode (XS) (20 m resampling)** • **Panchromatic mode (P) (10 m resampling)**

Table 1 SPOT Data Products and Its Characteristics ***continued;***

Preprocessing level	*Medium*	*Description*
2B	◆ CD-ROM ◆ CCT ◆ Standard film 241 mm x 241 mm. Scales 1:400.000 (full scene) and 1:200.000 (quarter scene) ◆ Paper print. Scales 1:100.000, 1:200.000, 1:400.000 (full scene) ◆ Paper print. Scales 1:100.000, 1:50.000 (quarter scene)	◆ Full scene or quarter scene ◆ Preprocessing level 2B (geometric corrections in cartographic projection with GCPs). Improved geometry and scene location accuracy. Points located by their rectangular coordinates using reference map grid marks. Pixel resampling (x and y axes) in a given cartographic projection. Pixel-to-pixel joining of two level-2 scenes. ◆ **Multispectral mode (XS) (20 m resampling)** ◆ **Panchromatic mode (P) (10 m resampling)**
	◆ Film 482 mm X 482 mm ◆ Scales 1:200.000 (full scene) ◆ and 1:100.000 (quarter scene)	◆ Full scene or quarter scene ◆ Preprocessing level 2B (geometric corrections in cartographic projection with GCPs). Improved geometry and scene location accuracy. Points located by their rectangular coordinates using reference map grid marks. Pixel resampling (x and y axes) in a given cartographic projection. Pixel-to-pixel joining of two level-2 scenes. ◆ **Multispectral mode (XS) (20 m resampling)** ◆ **Panchromatic mode (P) (10 m resampling)**
S1 and S2		◆ Full scene or quarter scene ◆ Preprocessing level S1 and S2 (radiometric corrections are performed as for level 1A and geometric corrections are performed as for level 2B).

Table 2 Planimetric and Height Accuracy Values Attained in Various Selected Tests

Reference	Experimental area	Ground Control Points	Hard/software	No. of Check Points	RMS in Plan	B/H	RMS in Height
***Hartley* 1987**	**Yemen**	7 from aerial triangulation	Kern SPOT software	116	29 m.	1	50 m.
		11 from aerial triangulation	Kern SPOT software	116	15 m.	1	14 m.
***Kratky* 1988**	**Ottawa**	6	Digital image processing and analytical plotter		4.9 m. in E 6.3 m. in N	0.4	12.2 m.
	Sherbrooke	9	Analytical plotter and BINGO modified		5.2 m. in E 5.8 m. in N	0.61	7.9 m.
	Grenable, France	5	Analytical plotter and BINGO modified		8.1 m. in E 5.8 m. in N	0.94	3.3 m.
***Rodriguez* 1987**	**South of France**	6-10	Traster/Metra analytical plotter SPOT software	86	6 m. in E 6.6 m. in N	0.5	7.1 m.
***El-Manadili* 1994**	**Nevada, USA**	6-8	Digital image processing developed software	10	10.6 m. in E 5.27 m. in N	0.8	5.55 m
	Colorado, USA	6-10	Digital image processing developed software	20	9.77 m. in E 6.68 m. in N	0.8	7.58 m.

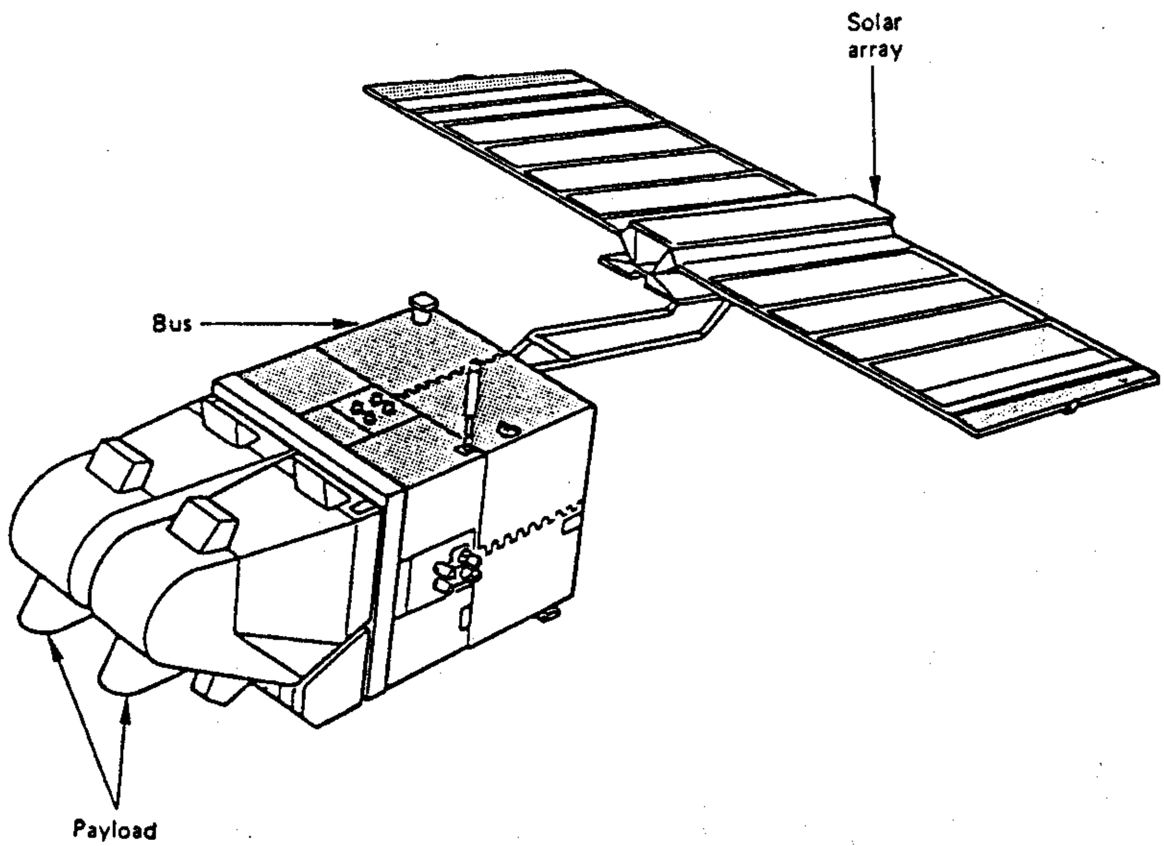

Fig. 1 *SPOT Satellite — General View*

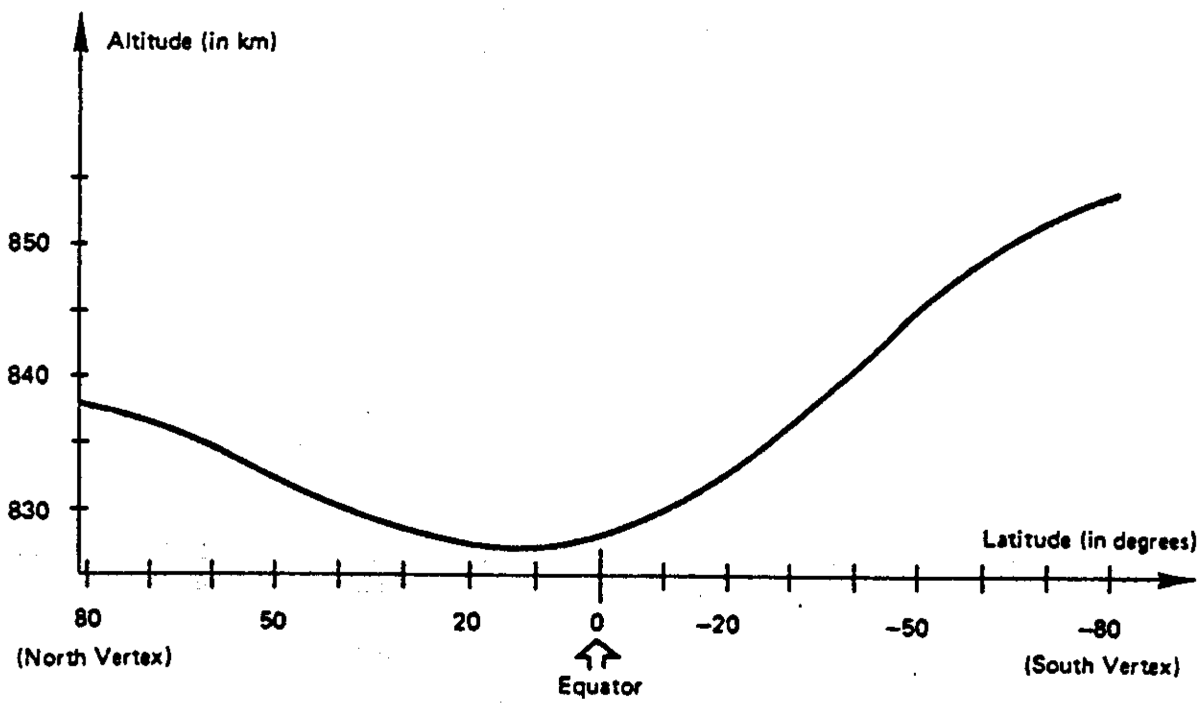

Fig. 2 Variation in SPOT Satellite Mean Altitude as a Function of Latitude

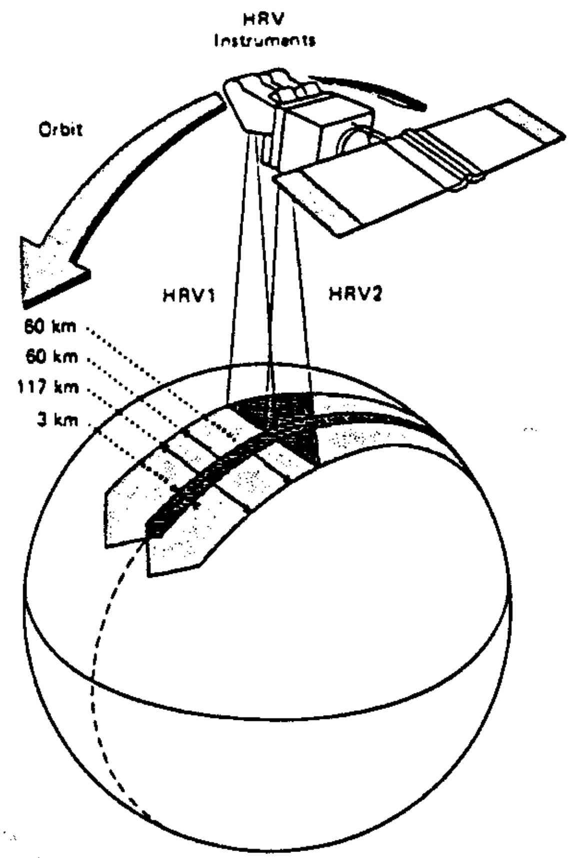

Fig. 3 Ground Strips Imaged by SPOT HRVs 1 & 2 in the Twin-Vertical Viewing Configuration

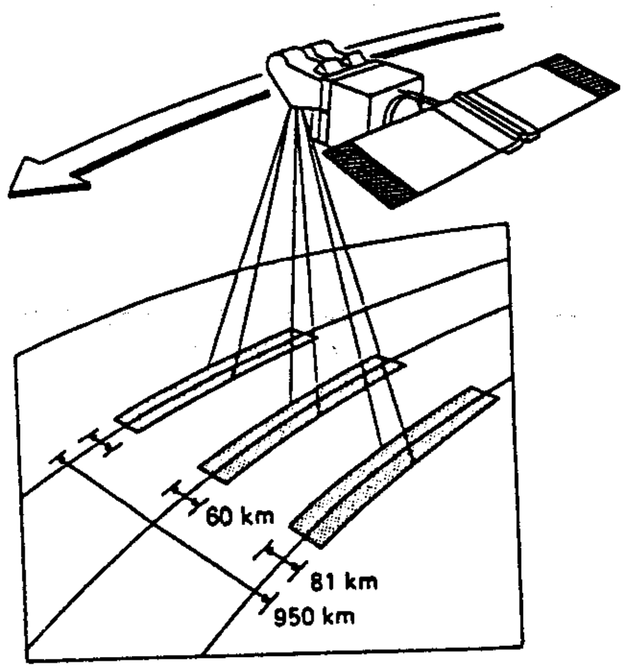

Fig. 4 Observable Corridor and Ground Strips Using Vertical and Oblique Viewing

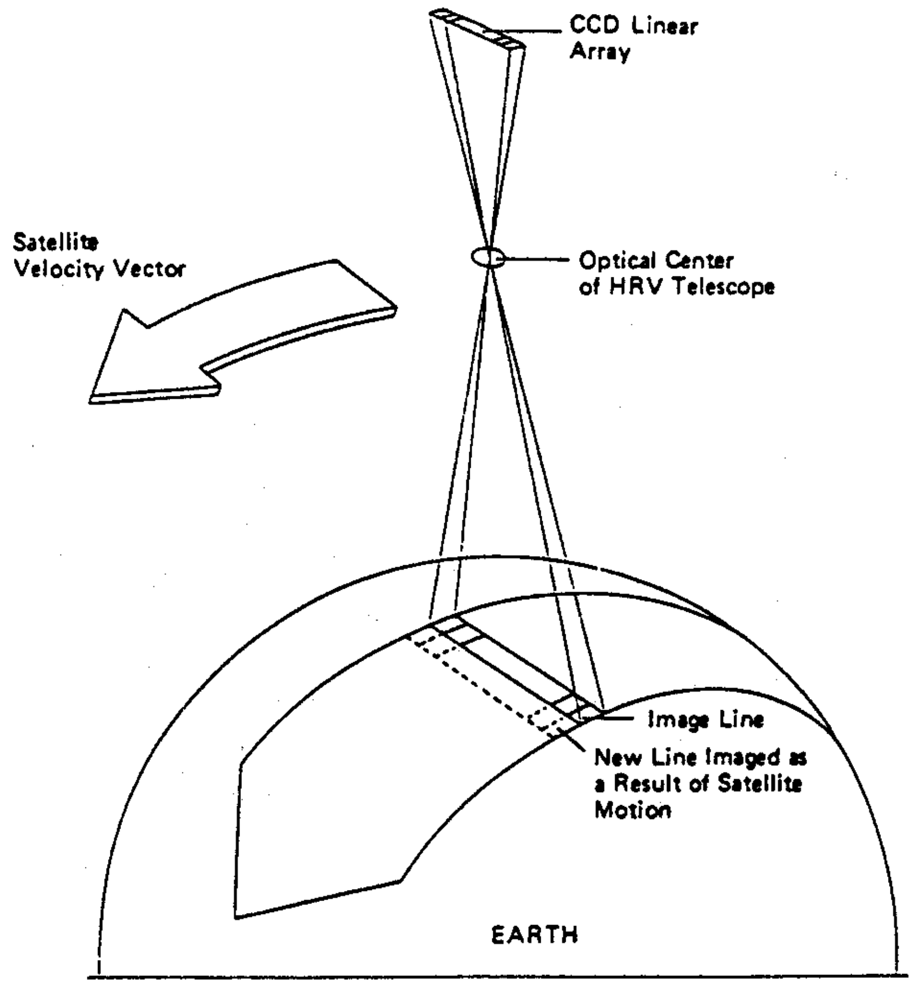

Fig. 5 . Push-Broom Scanning Principle

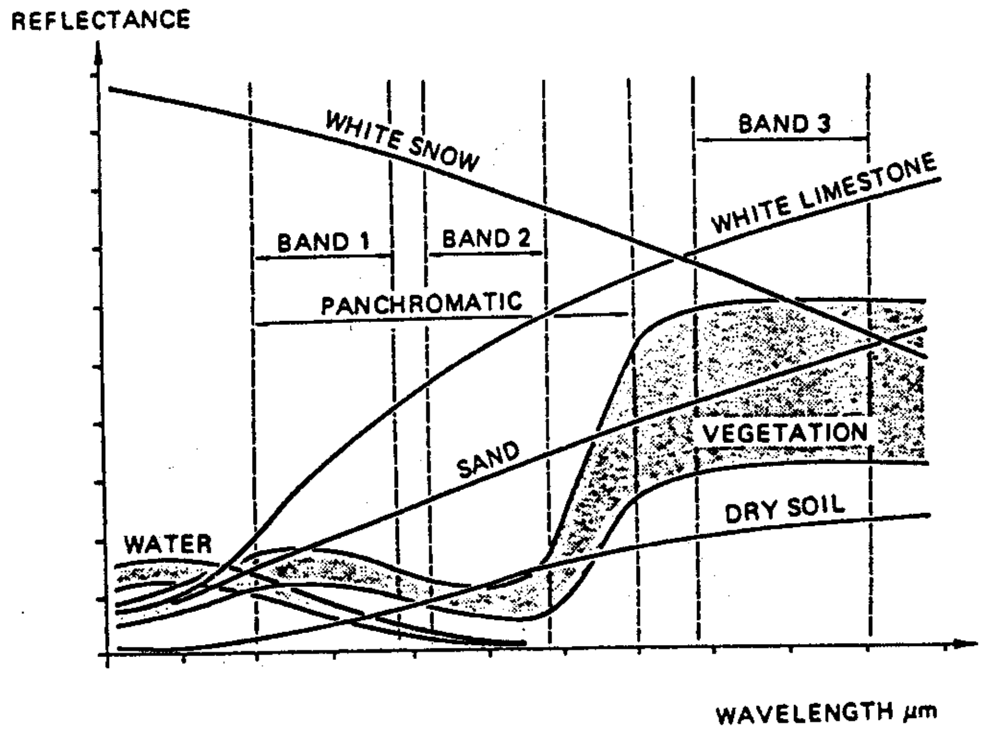

Fig. 6 *Typical Spectral Signatures and SPOT Spectral Bands*

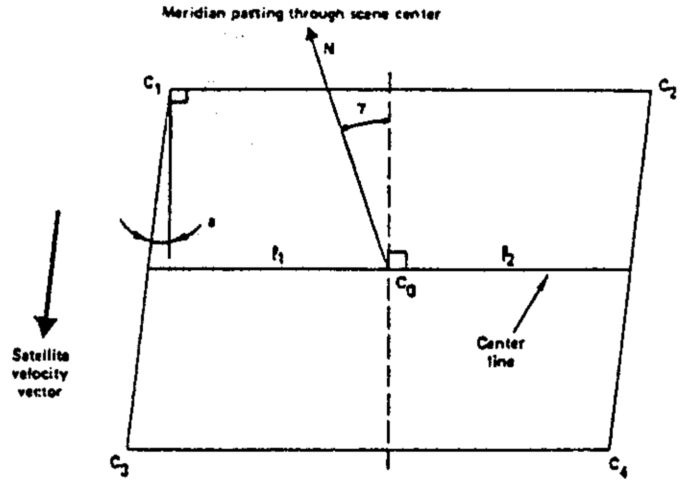

Fig. 7 a Scene Dimensions and Image Orientation

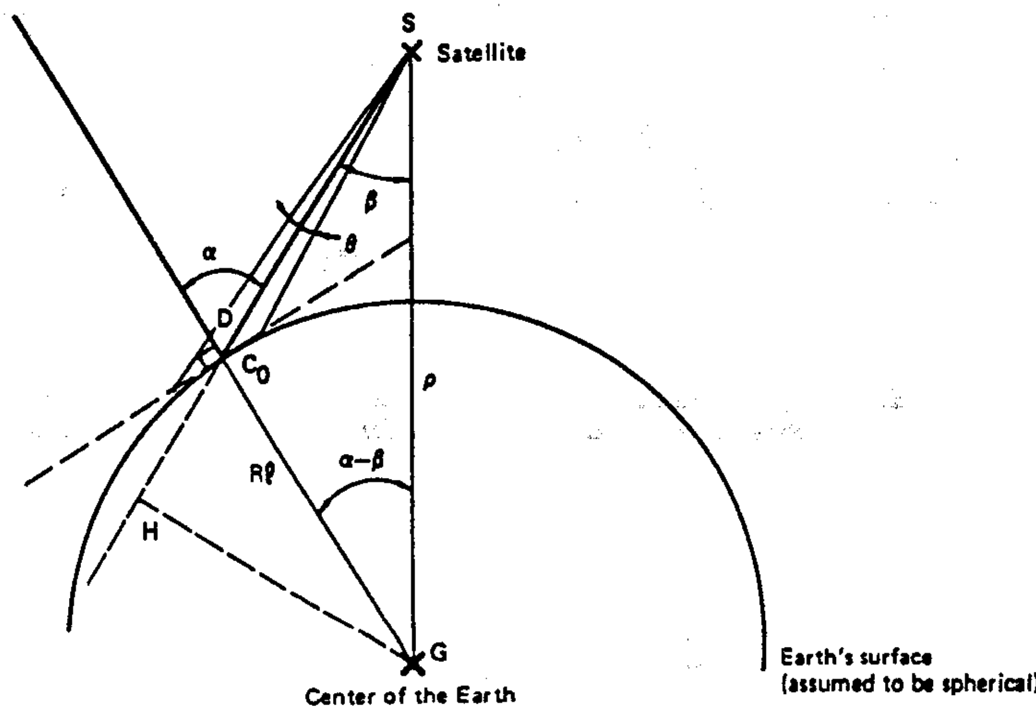

Fig. 7 b Angle of Incidence (α) and Viewing Angle (β)

Fig. 7 SPOT Image Geometry

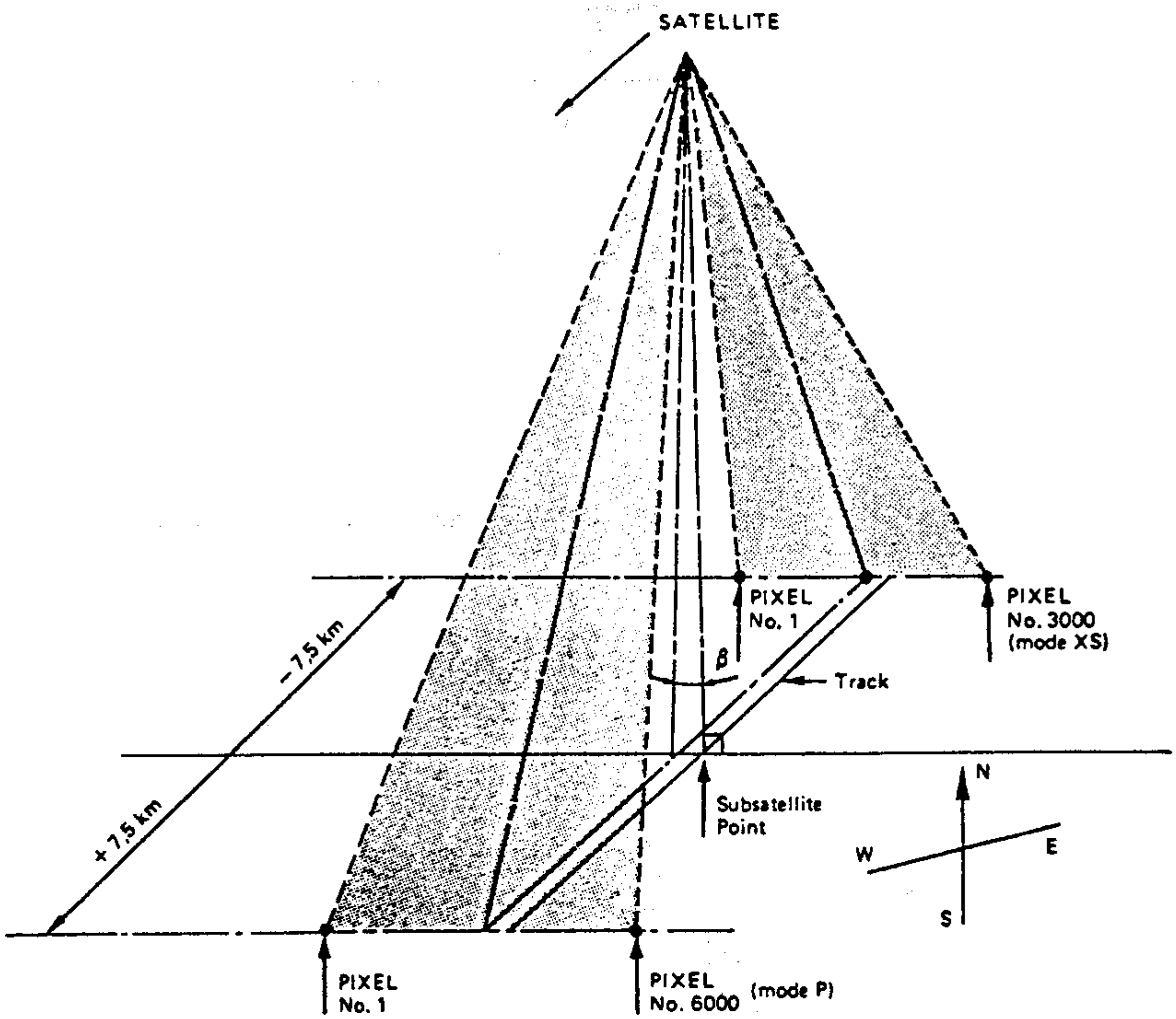

Fig. 8 Image Line Acquired At a Given Moment in Each Spectral Mode (Descending North-South Pass)

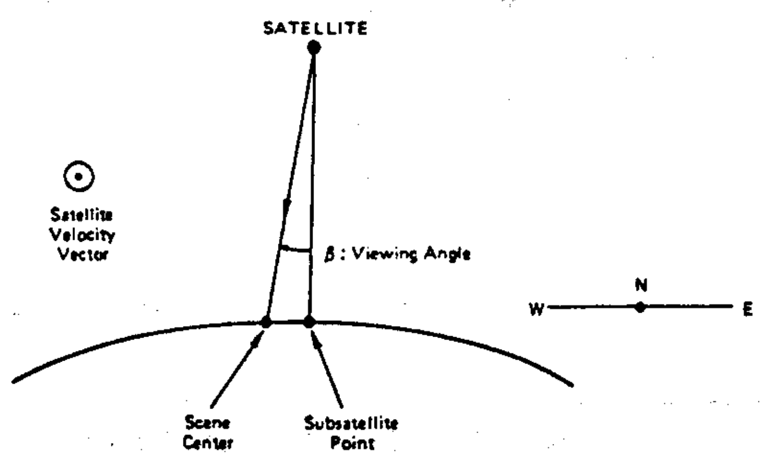

Fig. 9 Vertical Viewing

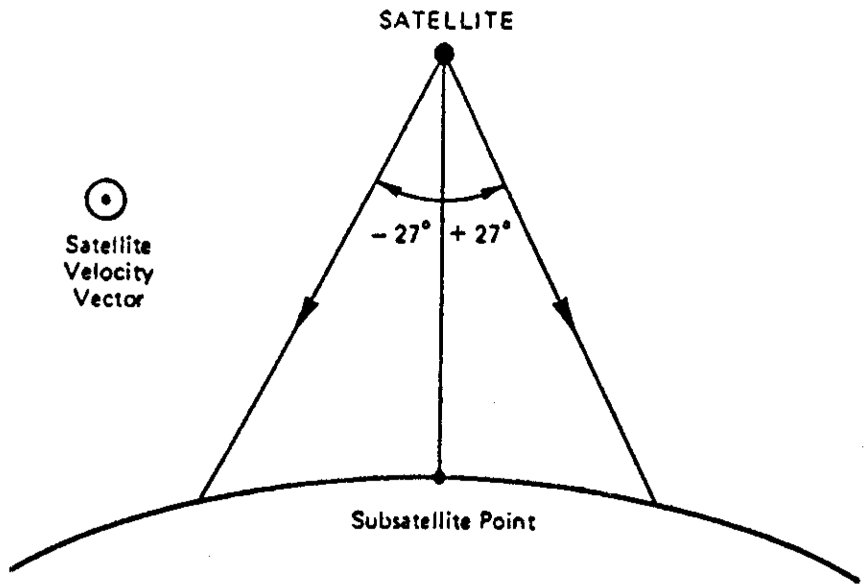

Fig. 10 ***Oblique Viewing***

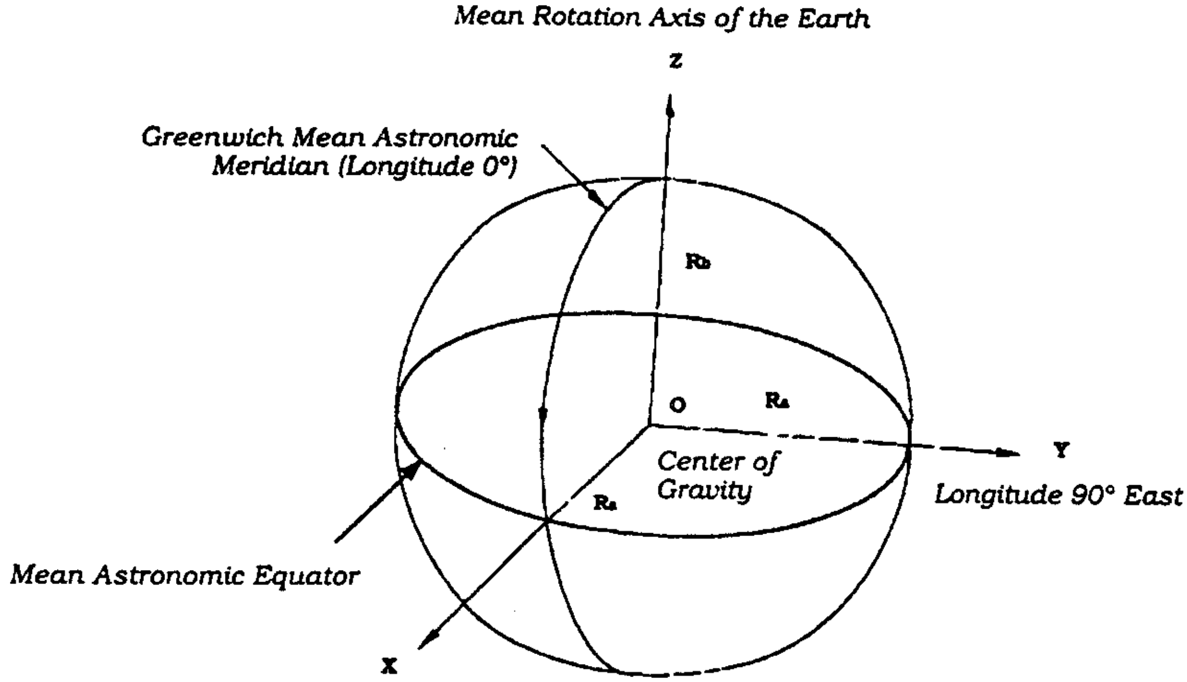

Fig. 11 1980 Reference Ellipsoids and 1980 Geodetic Reference System (GRS 80)

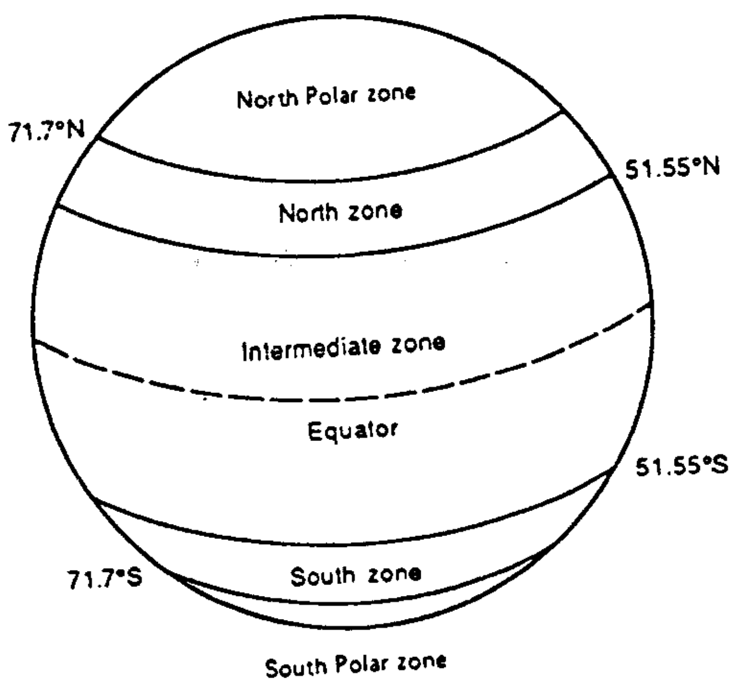

Fig. 12 Division of the Earth into SGRS Zones

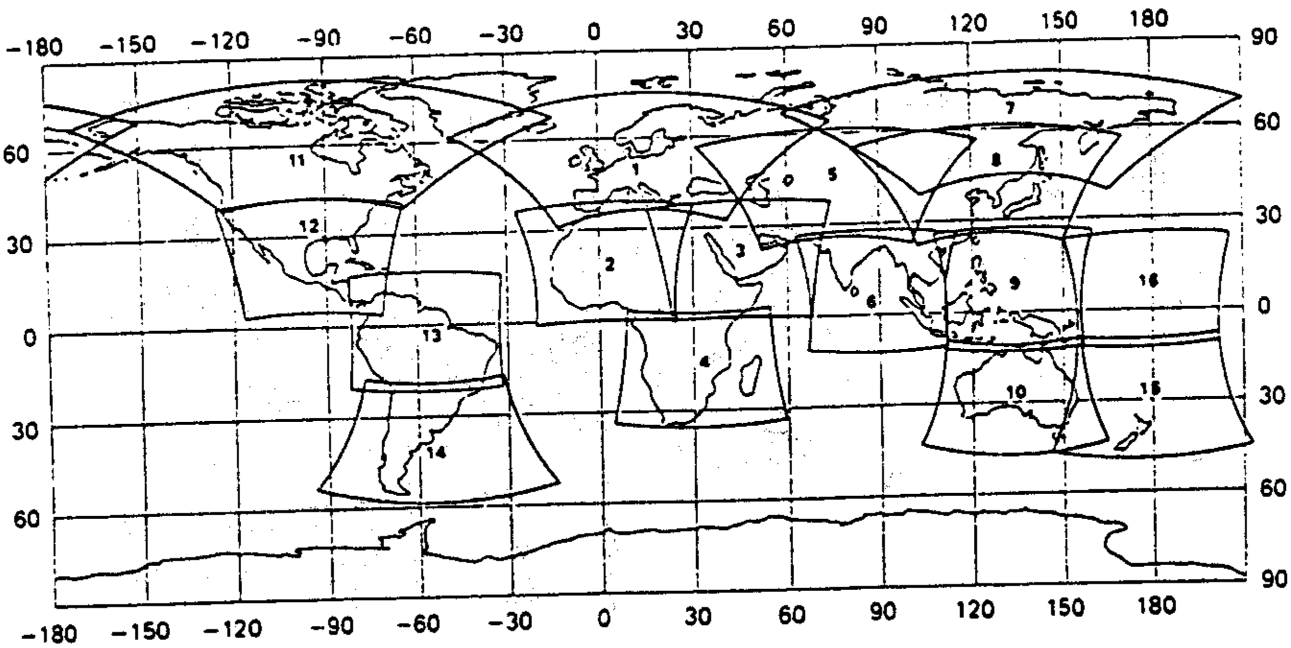

Fig.* 13 *Layout of the 16 SGRS Sheets

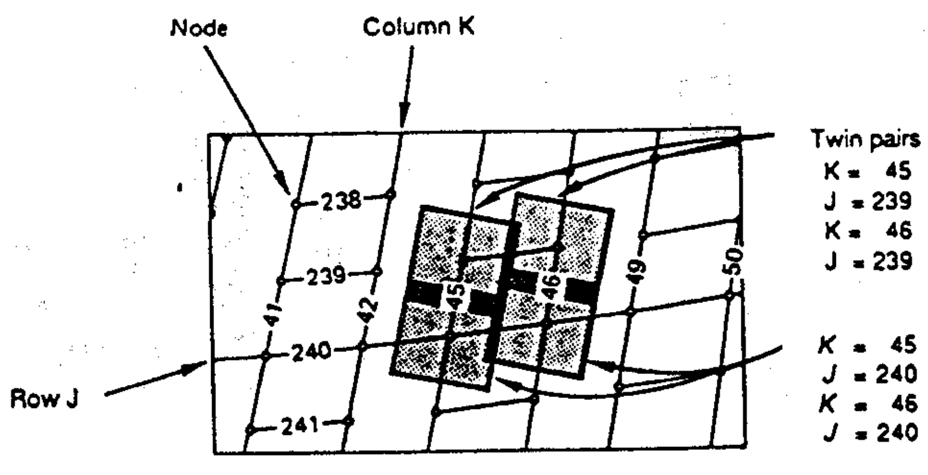

Fig.*14 *Description of a Part of SGRS (Two Pairs of Scenes Acquired in Twin Viewing Configuration)

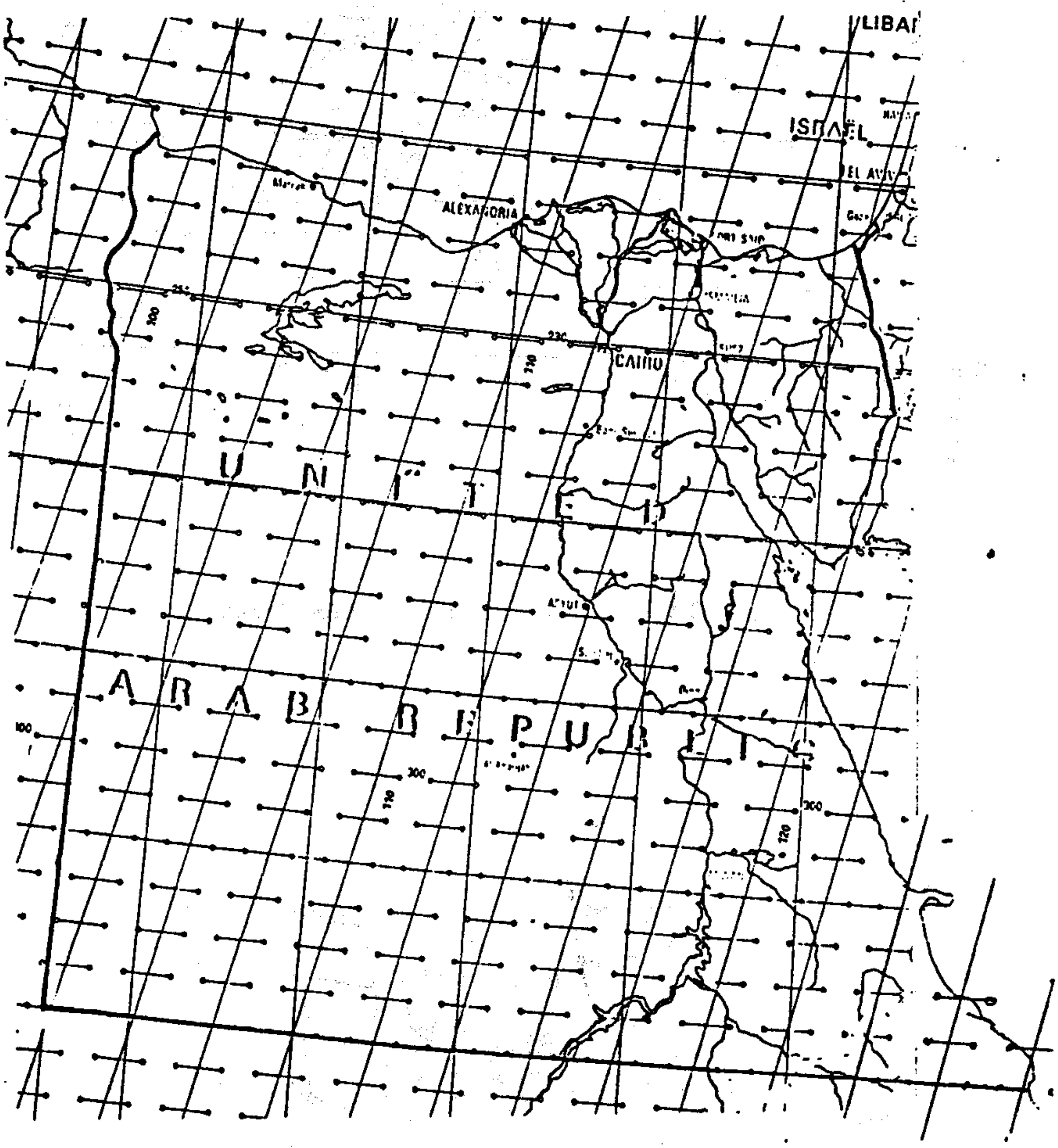

Fig. 15 ***SPOT Grid Reference System Over Egypt Territory***

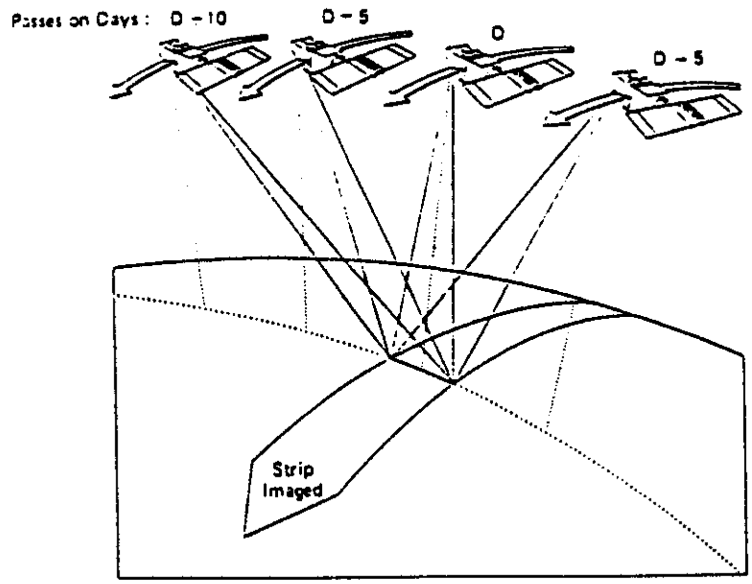

Fig. 16 a Frequent Acquisition Opportunities During a Given Cycle Using Oblique Viewing Capabilities

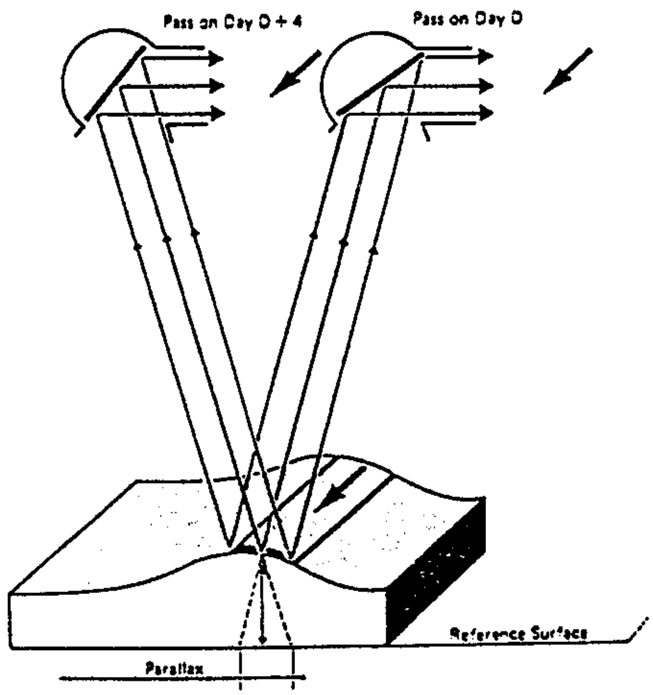

Fig. 16 b Stereoscopic Viewing Resulted From the Parallax Created by the Two Oblique Viewing Angles

Fig. 16 Stereopairs Acquisition