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WORKSHOP ON REMOTE SENSING TECHNIQUES WITH APPLICATIONS TO AGRICULTURE, WATER AND WEATHER RESOURCES

(27 February - 21 March 1989)

GEOMETRIC CORRECTIONS OF REMOTELY SENSED IMAGES

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Introduction

Geometric corrections is one of the preprocessing techniques. As preprocessing, we intend the corrections of the deficiencies and the removal of flaws present in the data prior of any use of them.

Some corrections are however carried out at the ground receiving stations, others have to be examined in this phase.

Preprocessing needs depend on the applications; techniques usually considered in this phase are data flaw corrections, radiometric corrections, atmospheric corrections, geometric corrections. Geometric corrections refer to spatial distortions of the spatial sampling grid; the others, instead, deal with alterations introduced in the radiance measured by the sensor.

Geometric corrections are however important not only to correct data but also to correlate information coming from different sources. In fact if we consider the example of two satellites with a different resolution we must adopt a common reference to correlate points from areas of the two resulting images. In the same way it is faced the problem to correlate a satellite image with an existing map.

Degradation causes

Among the degradation causes, rotation of the Earth, panoramic distortion, Earth curvature, finite scan rate of the sensor, sensor non-linearities, satellite altitude and attitude variations are the main. Some of them refer to a particular satellite or sensor and are corrected at the ground receiving stations. Others are more general and will be examined in the following.

Earth rotation

While the satellite is acquiring data, the Earth is rotating below it. The resulting effect is that a scan line has to be shifted with respect to the preceding one as showed in fig. 1. The amount of the shift is computed by considering the time t_s needed to acquire a frame. t_s is given by the dimension L_s of the frame along the orbit of the satellite divided by the velocity of the

satellite:

$$t_s = L_s/w_s r \qquad (1)$$

where w_s is the angular velocity of the satellite and r is the radius of the Earth.

On the other side the surface velocity of the Earth is given by:

$$V_e = w_e r \cos(L) \qquad (2)$$

where L is the latitude, and w_e is the angular velocity of the Earth. The total displacement to take into account between the first pixel and the last is:

$$d_e = V_e t_s \qquad (3)$$

A final consideration regards the fact that the satellite is orbiting with an inclination angle i. So, the effective displacement is also function of angle i:

$$d_i = d_e \cos(i) \qquad (4)$$

The total displacement, depending on the latitude and on the satellite parameters, can be some per cent of the total length of the frame.

Panoramic distortion

Consider as reference fig. 2. Since for spacecraft remote sensing platforms the angular IFOV is constant, the effective pixel size on the ground is larger at the borders of the scan line than at the subsatellite point. This effect is particularly evident for those satellites (the NOAAs for example) whose scan lines are particularly wide. In this way the effective resolution is maximum at the subsatellite point and decreases for lateral pixels.

Referring to fig. 2, if p is the pixel dimension at the subsatellite point, h is the height of the satellite, f is the angular IFOV, and v is the scan angle, we have that the length p_v' of segment AB is given by:

$$p_v' = fh/\cos(v) \qquad (5)$$

To have the effective pixel size p_v given by the length of segment CB we have:

$$p_v = p_v'/\cos(v) = fh/\cos^2(v) \qquad (6)$$

Eq. (6) gives the law by which resolution decreases when the distance increases from the subsatellite point.

A second effect is evident. Since p_v is the distance between the centers of the pixels on the scanning grid, when v increases, the reference grid is distorted. In fact, when we display our image, we use a regular reference grid; the effect is to compress the pixels which are at the borders of the scan lines. This distortion is evaluated by thinking that segment CS is seen as arc C'S' when considering the correct grid. The ratio between CS and C'S' gives the distortion factor:

$$D = v/tg(v) \tag{7}$$

Earth curvature

A further effect is due to Earth curvature; referring to fig. 3 we can observe that the curvature adds its effect to panoramic distortion. In fact we have now to consider that segment CB is rotated by an angle z with respect to fig. 2. Furthermore, to the height h of the satellite a term r(1-cos(z)) has to be added where, r is the Earth' s radius. The resulting formula is:

$$p_v = f(h+r(1-\cos(z))/\cos(v)\cos(v+z) \tag{8}$$

When z=0 eq. (8) reduces to eq. (6) as expected.

Geometric corrections

One way to define geometric corrections is to request that, after the transformation, the remotely sensed images have the scale and projection properties of maps.

A map is a graphic representation on a plane surface of the Earth' s surface or part of it, showing its geographical features. These are positioned according to pre-established geodetic controls, grids, projections and scales.

A map projection is the way to represent a curve surface on a flat sheet of paper.

Independently of the particular algorithm used to perform geometric corrections there are three main steps to be followed:

- Determine a relationship between the coordinate systems of the map and the image.
- Define a grid of points in the corrected image.

- Estimate the pixel grey level values associated with these points.

Two basic techniques have been proposed to solve the first two points of the algorithm. The former is based on the knowledge of the orbital geometry model of the satellite. A relationship between the coordinate system of the map and the image is mathematically computed and applied. This method is not particularly accurate since altitude and attitude parameters of the satellite are subject to vary continuously in time with the risk to apply a transformation whose parameters are not updated. The latter method ignores the causes of distortions and examines only the effects. Ground control points are identified on the map and on the image; from these points the needed transformation is defined.

Finally, resampling techniques are considered in order to solve the third point.

Orbital geometric model

As pointed out, it is based on the knowledge of the parameters of the orbit of the satellite, and of the sensor. Since it is not very accurate, it is usually applied only for those satellites which present a narrow angular field of view, as for example the Landsats'. We shall illustrate the procedure through an example which considers Landsat MSS data; the corrections applied are relative to scale change, skew, Earth rotation, and do not take into account panoramic distortion and Earth curvature. The corrections are applied by means of transformation matrices.

Scale Change

Landsat MSS presents four bands with a nominal IFOV of 79 m; the pixel size is nominally 56x79 m since there is an oversampling along the across-track direction. So, the pixel is not square but rectangular; this causes a distortion which can be eliminated by rescaling one of the two dimensions. Since the IFOV is 79 m, the best we can do is to perform a geometric rescaling to have a pixel of 79x79 m. This can be obtained by resampling the original image, thus defining a new grid in which points are more distant along the x axis with respect to the original of a ratio r = 79/56. The resulting transformation matrix T_1 to be applied to each point of the original grid is:

$$\begin{matrix} r & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

Skew correction

Satellite orbit is skewed with respect to the north-south axis of the Earth; if i denotes the inclination angle, the skew angle S_e at the equator is:

$$S_e = 90 - i \qquad (9)$$

where the angles are expressed in degrees.

The skew angle S is a function of latitude and is given by:

$$S = 90 - \cos^{-1}(\sin(S_e)/\cos(L)) \qquad (10)$$

where $\cos^{-1}$ indicates the inverse cosine function.

To obtain the north-south orientation, a rotation of the angle S has to be performed; the rotation matrix T_2 is:

$$\begin{matrix} \cos(S) & -\sin(S) & 0 \\ \sin(S) & \cos(S) & 0 \\ 0 & 0 & 1 \end{matrix}$$

Earth rotation correction

As pointed out in eq. (4) the rotation of the Earth causes a displacement to be taken into account. The correction to be applied to each pixel in the scanned image is a function of the scan time of that pixel or in an equivalent way of the pixel position. If d_i is the total displacement expressed by eq. (4), then the correction matrix T_3 is:

$$\begin{matrix} 1 & 0 & 0 \\ d_i r & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

where

$$r = t/t_s = i/N_p \qquad (11)$$

and t is the scanning time of the considered pixel, i is the i^{th} pixel which is acquired and N_p is the total number of pixels of the frame.

The three transformations defined above can be composed in only one transformation T:

$$T = T_1T_2T_3 \qquad (12)$$

These transformations can be applied to the various satellites by considering the orbital model and the characteristics of the sensor for each of them.

Transformations based on ground control points.

The method compares differences between the positions of points recorded on an image and on a map. These differences are used to estimate a set of transformations, between the image and the map and viceversa. The only drawback is that a map of the interested area has to exist. This is not true just in those areas where the need of maps is more urgent. A possible solution for these areas is to locate control points directly on the ground.

Once control points have been detected the transformation is individuated by using a least square method, depending on the model assumed for the transformation.

Let (x,y) and (c,r) the coordinates of a point in the map and in the image respectively. The simplest candidate transform is a linear one which relates one of the coordinates of a domain, to the twos of the other domain. The four transformations that it is possible to consider are:

$$\begin{aligned} x_i &= a_0 + a_1c_i + a_2r_i \\ y_i &= b_0 + b_1c_i + b_2r_i \\ c_i &= d_0 + d_1x_i + d_2y_i \\ r_i &= e_0 + e_1x_i + e_2y_i \end{aligned} \qquad (13)$$

Once the coefficients $a_0, a_1, \ldots, e_2$ have been determined the problem is solved. Each of eq. (13) has to be treated independently of the other and gives solution for its coefficients. Each ground control point gives origin to the set of eq. (13).

A linear transform of the form (13) can take into account scaling, rotation and translation. For panoramic distortion it is not sufficient since the distortion effect is more complex; higher order polynomials are necessary. The general form for such a polynomial is:

$$x = \sum_{j=0}^{m} \sum_{k}^{m-k} a_{jk}c^jr^k \qquad (14)$$

where m is the order of the polynomial. The other relations have a similar form.

Let us consider now the solution for the least square problem. We have to write eq. (14) for all the ground control points. For simplicity let us assume a 2^{nd} order polynomial and consider only the first of (13):

$$x_1 = a_{00} + a_{10}c_1 + a_{01}r_1 + a_{20}c_1^2 + a_{11}c_1r_1 + a_{02}r_1^2 \quad (15)$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$

$$x_N = a_{00} + a_{10}c_N + a_{01}r_N + a_{20}c_N^2 + a_{11}c_Nr_N + a_{02}r_N^2$$

which can be expressed in a matrix form as:

$$X = Pa \quad (16)$$

where

$$X = (x_1, \ldots, x_N)^T$$

$$a = (a_{00}, a_{10}, a_{01}, a_{20}, a_{11}, a_{02})^T$$

and

$$P = \begin{matrix} 1 & c_1 & r_1 & c_1^2 & c_1r_1 & r_1^2 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & c_N & r_N & c_N^2 & c_Nr_N & r_N^2 \end{matrix}$$

The solution of the problem is well known in literature and is given by:

$$a = (P^TP)^{-1}P^TX \quad (17)$$

where symbol $()^T$ indicates the transposition operation and $()^{-1}$ the inverse matrix.

The solution can be generalized for a N^{th} polynomial but it is quite rare to adopt a polynomial of order higher than third.

Solutions for the other transformations of eq. (13) are analogous.

Let now have some considerations on the choice and the number of ground control points. There is, in fact, a minimum number of ground control points; this number is determined by the number of coefficients of the polynomial representing the transformation. As we can see from eq. (14), 3 coefficients are necessary for a first order polynomial, 6 for a second order and 10 for a third order one. Correspondently, we need at least 3, 6, 10, equations to solve the problem. However if we required a least square solution, an higher number of points gives a better solution.

Just to give some ideas, for a full Landsat MSS image about 100 or 120 ground control points are needed. For a 512x512 image and a first order polynomial, experience suggests that 10-15 control points may be sufficient depending on the application and the precision requested.

The choice of the position of the ground control points is also particularly important. They have to be distributed as uniformly as possible on the image area. If not so, it may happen that some equation in (15) is a linear combination of the others. In this case problems appear when trying to compute $(P^TP)^{-1}$ in eq. 17. Really, when working with floating point numbers, it is rare that an equation is a linear combination of the others; what happens is that some equations are highly correlated, causing limitations to the precision of the results.

A note regards also what kind of control points to select; in fact, it is not convenient to choose control points which are subject to change with time. Due to the nature of maps, intersections of roads and buildings are good control points. Stable features are however a valid choice.

Once control points have been individuated on a map, they can be recorded for next use. The same can be done for the image. Though it is hard to believe that, when considering two images of the same area taken in different times, they maintain their image coordinates, some advantages can however exist. In fact a digital registration process is applicable between the two images and the displacement between couple of correspondent ground control points is valuable; from this displacement, ground control points in the new image are put into correspondence with the ground control points of the map which had been stored before. The registration process, depending on the relation between the two images, can be performed with various degrees of automation. Due to the great number of computations involved in registration, it is however important to take advantage from any a-priori interactive information aimed to restrict the correlation area and so the computational effort.

Resampling

Once defined the coordinate transformations between map and image, it is also defined the grid of points of the image, by applying the transformation to the map grid. So, for each point in the coordinate map system, we apply the transformation and compute the correspondent coordinates in the image coordinate system. We associate the grey level of these points to the points in the map coordinate system and the process ends. This is not unfortunately so. In fact, when computing the image coordinates, we obtain in general two floating point numbers, while the starting image coordinates are integer: a pixel does not usually exist at the computed coordinates. This is not, however, a real problem, since it is sufficient to interpolate the original image and pick up the interpolated grey level value.

Usually three types of interpolations are adopted: nearest neighbour, bilinear, bicubic.

Nearest neighbour interpolation is the simplest way to tackle the problem. The grey level of the pixel whose coordinates are rounded values of the computed ones, is assumed and reported on the corrected image. This is quite effective; the only drawback is a sort of blocking effect in the output image.

Bilinear interpolation associates in the output image a weighted mean of the four pixels which are in proximity of the computed image coordinates. If r, c are the computed coordinates, $v_{i,j}$, $v_{i,j+1}$, $v_{i+1,j}$, $v_{i+1,j+1}$ the grey levels of the four neighbouring pixels, the resulting grey level value V is given by:

$$V = (1-a)(1-b)v_{i,j} + b(1-a)v_{i+1,j} + a(1-b)v_{i,j+1} + abv_{i+1,j+1} \quad (18)$$

Where

$$a = c - |c| \qquad b = r - |r| \quad (19)$$

and | | indicates that the integer part of the number has to be considered.

Bicubic interpolation is based on the fitting of a 2-D third degree polynomial surface to the area around the coordinate (c,r). In this scheme the 16 pixels which are in proximity of coordinates (c,r) are used. The process acts in two steps; first the interpolation is performed in one of the row or column directions, then in the other. The interpolation formulas are:

$$V_{c,m} = -a(1-a)^2 v_{j-1,m} + (1-2a^2+a^3)v_{j,m} + a(1+a-a^2)v_{j+1,m} - a^2(1-a)v_{j+2,m}$$

where m = i-1, i, i+1, i+2 and a (and b) is defined in (19).

The intermediate values $V_{c,m}$ are used in next expression:

$$V_{c,r} = -b(1-b)^2 v_{c,i-1} + (1-2b^2+b^3)v_{c,i} + b(1+b-b^2)v_{c,i+1} - b^2(1-b)v_{c,i+2}$$

Fig. 1

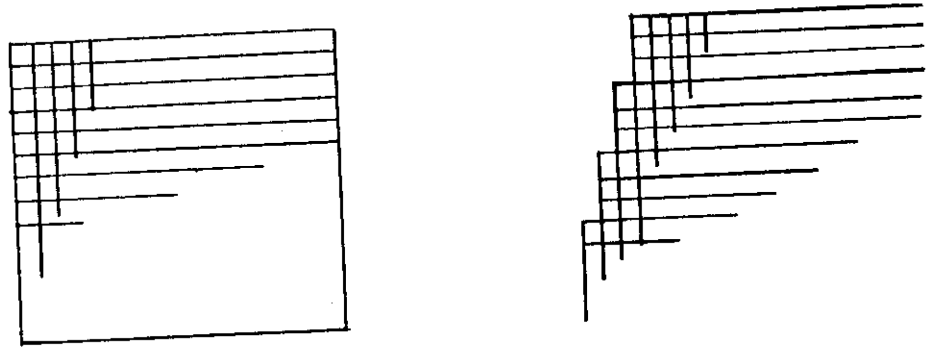
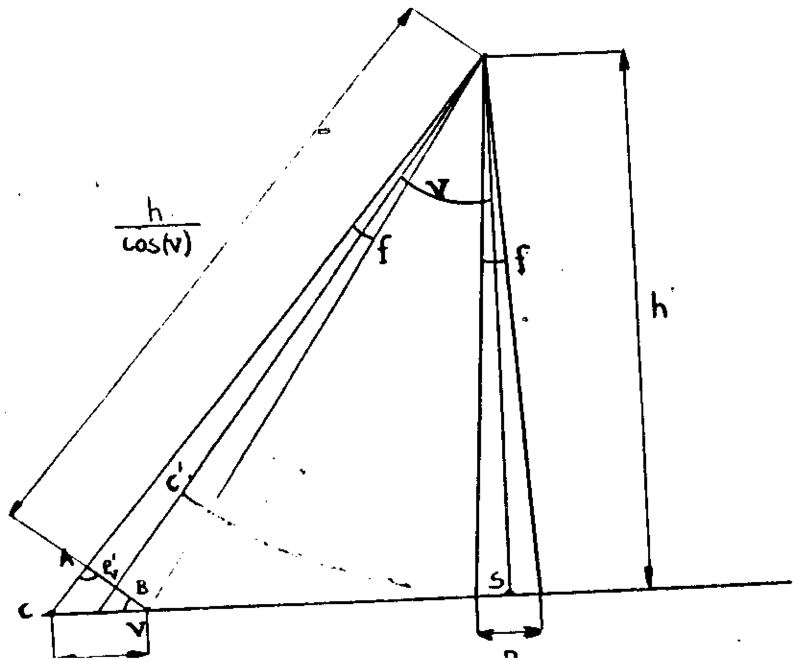


Fig. 2



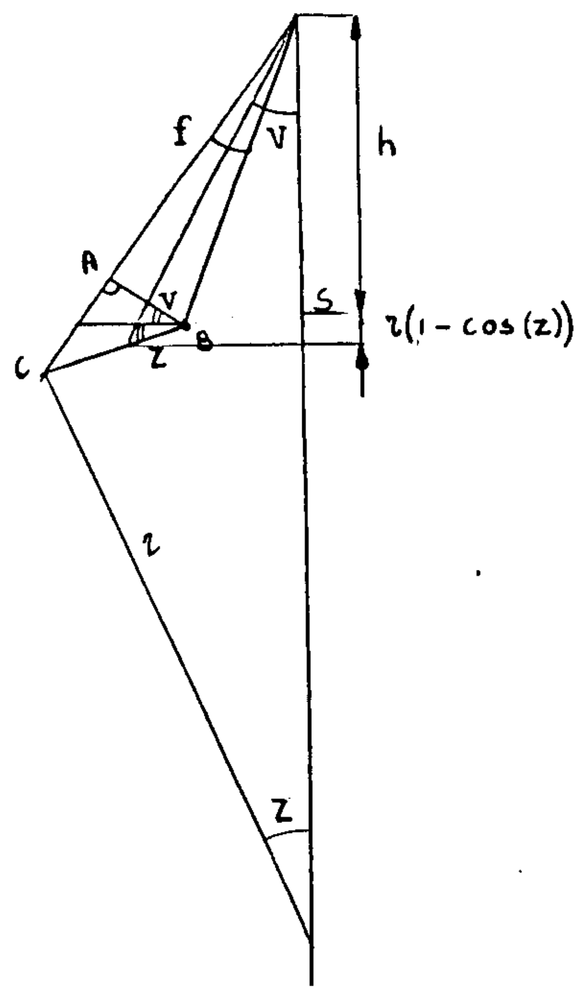


Fig. 3

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TRANSPARENCIES

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1

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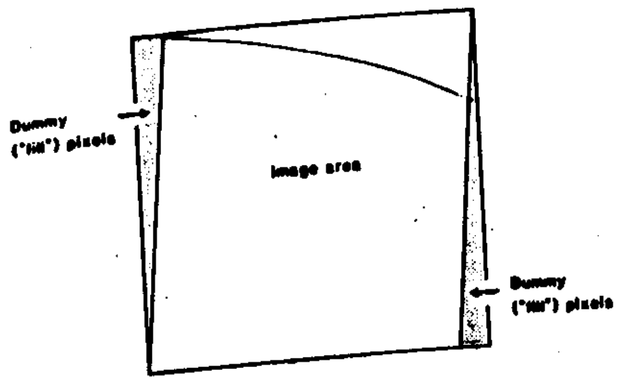


Figure 3.11 Fill or dummy pixels added to start and end of image data records to compensate for Earth rotation during scanning.

— finite scan rate of the sensor.

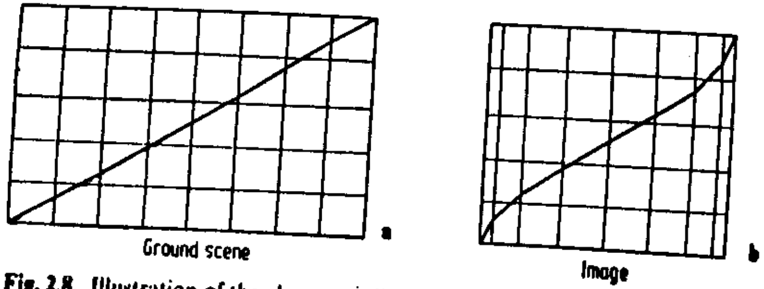


Fig. 2.8. Illustration of the along scan line compression evident in constant angular IFOV and constant angular scan rate sensors. This leads to so-called S-band distortion, as shown

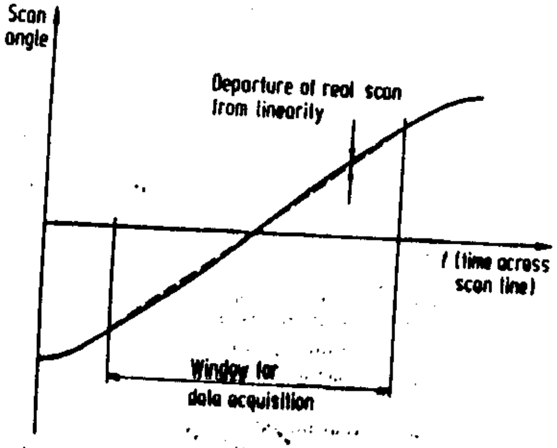


Fig. 2.11. Mirror displacement versus time in an oscillating mirror scanner system. Note that data acquisition does not continue to the extremes of the scan so that major nonlinearities are obviated

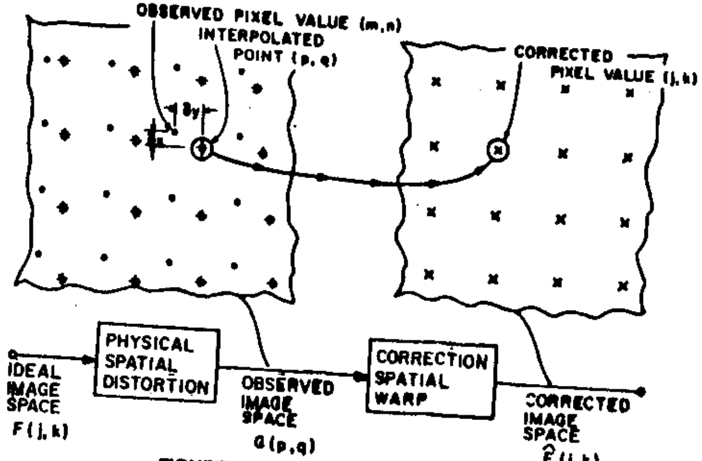


FIGURE 15.3-2. Spatial warping concept.

BASIC GEOMETRIC TRANSFORMATIONS

- Translation
- Rotation
- Scaling

$$[x' \quad y' \quad 1] = [x \quad y \quad 1] \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

SCALE CHANGE

$$X' = X\,S_X$$

$$Y' = Y\,S_Y$$

$$|X' \quad Y' \quad 1| = |X \quad Y \quad 1| \begin{vmatrix} S_X & 0 & 0 \\ 0 & S_Y & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

ROTATION (Around the origin)

$$X' = X \cos(P) + Y \sin(P)$$

$$Y' = -X \sin(P) + Y \cos(P)$$

$$|X' \; Y' \; 1| = |X \; Y \; 1| \begin{vmatrix} \cos(P) & -\sin(P) & 0 \\ \sin(P) & \cos(P) & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

TRANSLATION

$$X' = X + T_X$$

$$Y' = Y + T_Y$$

$$|X' \; Y' \; 1| = |X \; Y \; 1| \begin{vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_X & T_Y & 1 \end{vmatrix}$$

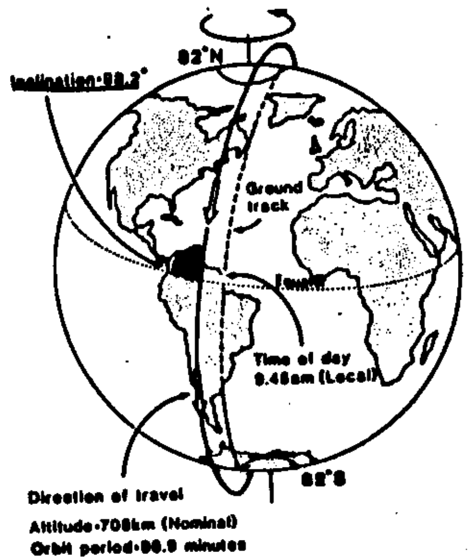
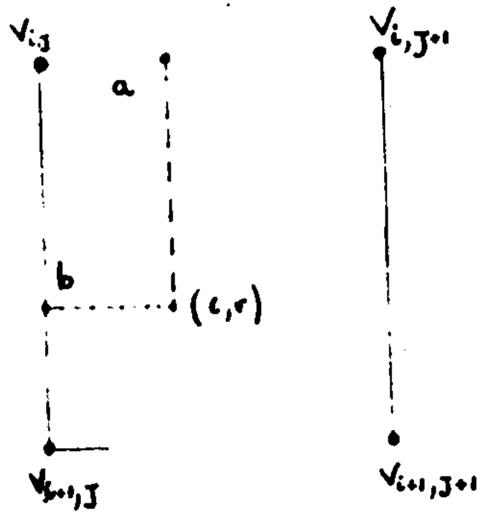


Figure 3.8 Landsat-4/5 orbit.

BILINEAR INTERPOLATION



$$V = (1-a)(1-b)\,v_{i,j} + b(1-a)\,v_{i+1,j} + a(1-b)\,v_{i,j+1} + ab\,v_{i+1,j+1}$$