CHAPTER IV

4.1 Introduction

One of the most important data structures used for spatial analysis is a Digital Elevation Model (DEM), which is a digital representation of the Earth's topography - for example, a matrix containing the height of points on the Earth's surface above some reference datum. DEMs have traditionally been produced by digitising map contours derived from stereo-pairs of aerial photographs. (Jonathan, 2001)

Unfortunately, DEMs of usable detail are still not available for much of the Earth's surface (such as deserts, mountain ranges and other inaccessible regions), and even when available may not be of sufficient accuracy, or may suffer from problems of inconsistency of data acquisition and processing methodology. Faced with the increased global demand for DEMs, satellite data provides a realistic source for all but the finest grid DEMs - and with the advent of Very High Resolution (VHR) images.

Digital elevation models or DEMs are increasingly becoming the focus of attention within the larger realm of digital topographic data. This is essentially due to the fundamental nature of the data, and knowledge pertaining to that data, they represent. The quality and calibre of that knowledge is becoming extremely valuable in the numerous applications within the earth, environmental and engineering sciences. This is attributable, at least in theory, to the precision of a DEM in simulating the true terrestrial parameter of elevation, slope and aspect. Global change science research and applications, for example, are an area where need for quality topographic data is an imperative requirement. DEMs are a typical example of such a requirement.
4.2 Digital Elevation Model

The form of surface model used for this entire study is that of the Digital Elevation Model (DEM). Although the term is used inconsistently in the literature (Burrough, 1986; Weibel and Heller, 1991), it is strictly defined here consistent with the terms of Burrough (1986), as a regular gridded matrix representation of the continuous variation of relief over space. A Digital Elevation Model (DEM) provides a digital representation of a portion of the earth's terrain over a two dimensional surface. A DEM is normally generated by sampling a regular array of elevation values derived from topographic maps, aerial photographs or satellite images. Opinion differs over whether "terrain" should be used in place of "elevation" in a DEM. Elevation is preferred when only relief is represented whereas terrain is used to imply attributes of a landscape other than the altitude of that landscape.

4.3 Digital Terrain Model

Digital Terrain Modelling (DTM) is a system of quantitative methods to analyse and model the land surface and relationships between the topography and geological, hydrological, biological and anthropogenic components of landscape. Digital terrain modelling is a part of quantitative geomorphology (Florinsky, 2002). Digital Terrain Models (DTMs) are digital representations of variables describing the topographic surface. Using terrain, allows for the possibility of including landscape attributes other than topography as a means of improving the digital representation of a section of terrain. The functional significance of using DTM could therefore imply a digital model of any single-value surface (population density, cost surface, or erosion potential).

4.4 Methods in deriving DEMs from Satellite imagery

The most common method used to derive DEMs from satellite images is to use the parallax information present in a pair of images viewing the same scene at different angles. This is to the way that the human visual system obtains three-dimensional information (Fig. 7). A single human eye is essentially a two-
dimensional sensor – it can move elevationally (up and down) and azimuthally (side to side) relative to its position in the head.

Figure 7. The human visual system: the two eyes are fixated on the nearer rod; the more distant rod produces a binocular disparity (a larger distance between the images of the rod and the fovea of the left eye compared to that of the right eye). This effect is illustrated by the corresponding pair of rods below each eye (Frisby 1979).

The angular location of any object viewed by a single eye can thus be specified by the two angles describing the ray of light from the object to the eye. This, in itself, is not sufficient to retrieve three-dimensional information; however, the information from the right eye also determines another ray that the point must lie. The combined attitude information from both sensors together with their known configuration in the baseline of the human skull enables the brain to calculate the true three-dimensional location of the point.
The basic requirement of satellite stereo viewing is that the sensor should capable of viewing the same point on the earth from two different angles.

4.4.1 Designing the instruments for stereo image

Generally, satellite stereo images can be acquired by two different ways i.e. across track and along track stereo. IRS-1C PAN is a typical example of across track stereo. In along track, stereo images are derived using views acquired at different angles along the line of the orbit. These can be forward, backward or vertical from a single viewing instrument or by using several instruments pointed at different angles in the plane of the orbit. The concept of along track stereo will be used in the future IRS program i.e. CARTOSAT-1 or IRS-P5. This will carry two identical high resolution cameras pointed along track for at +26° (forward) and aft at -5° (backward) respectively. Already this method of acquiring stereo images is used in the German Modular Opto-Electronic Multi-Spectral Stereo Scanner (MOMS), the Advanced Thermal Emission and Reflection Radiometer (ASTER).

The main advantage of along track stereo is that images are acquired with a very small temporal separation, typically of an order of minutes, whereas the across-track images are acquired in different dated i.e. typically from 1 day to its repeat cycle. This means that the images will have very similar atmospheric and surface characteristics, as well as an easily modelled geometry, leading to more effective stereo-matching and potentially more accurate generation of DEMs in case of along track stereo compared to across track stereo.

The across track stereo has the advantage that the Base-Height (B/H) ratio can be varied (in the same way in IRS-1C PAN across track stereoscopy) and provides the operational benefit of lighter payload. Using fixed pointing sensors like CARTOSAT-1 means that only a fixed B/H ratio is obtainable from any pair of instruments.
4.4.2 Selection of algorithms for deriving height information

4.4.2.1 Photogrammetric methods of Height extraction

One simple method of deriving height and contour information from IRS-1C stereo pair is to reproduce the left and right hand images photographically and use standard photogrammetric techniques, such as the use of an analytic stereo plotter to produce the desired information. Unfortunately, IRS-1C image is somewhat different from aerial photograph and such techniques are not directly applicable.

4.4.2.2 Digital Stereo Matching

Apart from the standard photogrammetric techniques to derive height information, it is desirable in terms of both operator involvement and the ultimate accuracy of the product, to generate the DEMs entirely by digital means. There are two main aspects to this i.e. first is the imaging geometry, the model based solution is required and the second is image correspondence, which is concerned with the location of the same feature in both images and the calculation of the stereo disparity between them. There are two classes of algorithms for solving the correspondence problem: the first class is based on mathematical correlation of image areas; the second is based on featured techniques such as those used for computer vision. In addition, various hybrids of the two approaches are possible.

4.4.2.2.1 Correlation Methods

The correlation approach to stereo matching (Greenfield 1991) relies on certain assumptions about the problem domain, i.e.

- It is possible to pre-define a coarse mapping between the two images.
- The radiometric properties of the two images are similar.
- There are no unmodelled geometric distortions between the image geometries.
• Two image patches to be matched, have distinct textures.

The steps necessary for production of DEMs using the correlation approach can be described in broad terms as follows:

1. Acquire a suitable stereo pair with sufficient Base-Height (B/H) ratio.
2. Calculate the imaging geometry for the left and right hand image.
3. For each point, determine the stereo disparity.
4. Calculate the height from the stereo disparity.
5. Perform any interpolation necessary.
6. Reformat onto the final DEM grid.

4.4.2.2 Feature-based methods

The other approach to the stereo-matching problem is to use feature-based methods, based on techniques of computer vision. The use of computer vision techniques to model 'real-world' features has certain potential advantages. Correlation algorithms can be restricted by their underlying radiometric and geometric constraints and can suffer from 'loss of lock' when they fail to converge. In human vision, the most important low-level component is generally considered the detection of edges, since the boundary between two features will often be accompanied by a significant change in image intensity over a very small distance; and the problem of edge detection is fundamental to computer-based image interpretation. The 'edge detector' thought to be employed in the human visual system can be approximated by several Difference of Gaussian (DoG) filters applied to an image (Kauffman and Wood 1987). Conceptually each DoG filter is used to detect edges that occur at a different spatial frequency and thus can be used to detect edges at a wide variety of separations; unlike the Laplacian or other kernel-based filters which are often restricted to edges at a 'one pixel' frequency.

Various approaches to feature matching are possible (Fig. 8), the key
components in such a matching system being (Greenfeld 1991):

- selection of matching primitives.
- method for extracting primitives (for example, the particular edge detection algorithm used).
- the selection of a suitable search/prediction strategy.
- methods for assessment of results.
- quality-control and consistency measures.

A typical first step is an image preparation stage, which takes the raw digital stereo images and performs the necessary image rectification to produce a corrected vertically registered stereo pair. This is then followed by a boundary extraction phase to extract features from the image pair, which are invariant to radiometric effects, such as differences in illumination conditions. One approach is to use DoG filters; applied to the entire image, to detect a candidate set of edge locations to sub-pixel accuracy by the positions of zero crossings (it is generally much easier to determine the position where a function crosses an axis than to determine the maximal location of a characteristically flat correlation peak). The edges are subsequently validated to remove effects of sensor noise, scene noise and characteristics of the DoG filters.

The objective of the boundary-matching phase is to determine, for each boundary in the left-hand image, the corresponding boundary in the right-hand image. The algorithm starts with the boundaries produced by the largest DoG filters, which will provide the coarsest measure of boundary location. For each feature detected in the first image the best match feature in the second image is determined. Because both features are stored in a symbolic vector format rather than as raster patches, the matching process is far less computationally intensive. Once the matching boundaries have been detected, the stereo disparity between the two boundaries is calculated, typically at separations of one pixel.
Once the initial coarse stereo disparity has been calculated, the same process can be repeated at each resolution level as the algorithm focuses into the disparity at the finest resolution. This hierarchical 'coarse-to-fine' matching system exploits the relationship between adjacent levels to provide a natural description of image features proceeding from the largest attributes down to the finest discernible image detail; this again is a reasonable approximation of how the human visual system operates on a number of hierarchical scales depending on the symbolic nature of the feature being processed. The actual matching criteria are based on a statistical similarity score between the two boundaries being compared; this is followed by the selection of the best such match.

When this has been achieved at the finest level of detail, the stereo parallax for each boundary-pair is calculated. Thus the result of the boundary-matching phase is the set of matched boundaries and the stereo parallax associated with them. Depending on the algorithms used, these will be a measure of the stereo disparity at the edges of significant features or alternatively throughout a control network. As with correlation-based methods geometrical modelling can now be used to generate the final DEM - it may also be necessary to use an interpolation algorithm to convert from a feature-based to a grid-based product.

### 4.4.2.2.3 Hybrid approach

Either a correlation or feature-based approach may successfully produce a DEM, but possible disadvantages are inherent in each method. For example, the correlation method may fail to find sufficient successful matches to produce a DEM, or the feature-based approach may produce good results for identified features - but produce no elevation values at intermediate points. Other problems encountered with correlation-based methods (Kauffman and Wood 1987) include:

- problems with non-linear grey-level effects encountered with off-nadir viewing.
Figure 8 A possible approaches to feature-based DEM generation

- the effect of different lighting conditions.
- use of algorithms with limited pull-in range, which rely on accurate seeding.
To date there has been a certain reluctance to use hybrid approaches with most practitioners firmly in the correlation or feature-based techniques. Despite this point-of-view and the corresponding opinions of the 'correlationists', it would seem beneficial to investigate approaches, which make the most of the strengths of each class of algorithm. There are two main types of hybrid-processing schemes:

- **One-step methods** where (for instance) a preliminary DEM is produced by feature matching and the fine details are determined by correlation.
- **Adaptive methods** where an 'intelligent' controller determines the most appropriate method for a particular situation.

One example of the simple hybrid approach is to use a feature-based method (Barnard and Thompson 1980) to provide the seed points for a Gruen algorithm (Day and Muller 1988). The Barnard and Thompson feature matcher uses an 'interest operator', which can produce results to the order of pixel accuracy. This is sufficient to be within the pull-in range of the Gruen algorithm, which completes the job to sub-pixel accuracy. A similar approach was used for an experimental system to compare the three approaches to stereo matching; this system consisted of an area-based module, a feature-based module and a hybrid module, which used the feature-based method to seed the area-based module.

An example of second method is the approach proposed in a stereo-matching system, which uses a variety of techniques (Greenfield 1991). The basic structure of the system is shown in Fig. 9.

The first phase of the matching is performed by an edge-matching process. Subsequently a central monitoring system can invoke one of three additional matching processes:

- a correlation-based algorithm
• an 'interest operator'
• an interpolator.

This approach is an enormous challenge in digital photogrammetry (Greenfield 1991) but promises to yield an effective, robust stereo-matching system which requires a minimal amount of operator intervention.

4.5 Height Information from Space borne RADAR

Although the state-of-the-art may not be as advanced as that for optical images, there is great potential in the production of DEMs from space borne radar. One of the benefits in using radar is that it measures distances directly, whereas optical sensors measure angles subtended by targets, which have to be subsequently converted into distances. The two radar instruments that have potential for DEM production are Synthetic Aperture Radars and Radar Altimeters. Altimeters have been successfully flown on missions such as Seasat and ERS-I and are capable of measuring height to within a few centimetres; however, due to their large footprint, they are not suited for production of local-scale DEMs, and most research and development to date has concentrated on height-extraction from SAR.

SAR has been successfully flown on missions in RADARSAT. There are three categories of information inherent in a SAR image (Polidori 1992):

• geometric information in terms of range and azimuth
• information from the phase of the radar signal
• radiometric information from the back scattered signal.

Each source of information gives rise to a different method of height determination:

• stereo matching (radargrammetry)
• SAR interferometry
Operational flow lines for the derivation of height using each of the above methods are shown in Fig. 10.

4.6 The Importance and Need for DEMs
DEM are used in a number of applications in the earth, environmental and engineering sciences. Their earliest use dates back to the 1950s since which time, they have proved to be an important method for modelling and analysis of spatial-topographic information. Broadly, there are five main application domains.
where DEMs are utilized: civil engineering, earth sciences, planning and resource management, surveying and photogrammetry, and military applications.
4.7 Terrain Modelling and Analysis using IRS-1C PAN Stereo data

The spatial resolution, the radiometric resolution and the geometric quality of the data broadly limit the application potential of the satellite imagery. Major causes of geometric inaccuracies are errors in knowledge of satellite orientation and the terrain undulations. The random ground height variation poses major difficulties in remote sensing data processing for cartographic applications. Error in satellite orientation can be modelled and estimated precisely by using Ground Control Points (GCP) and the errors due to terrain undulation can be corrected using Digital Elevation Model (DEM). The DEM can be derived either by digitizing a map or from a stereo pair acquired by a satellite with a high resolution sensor onboard. Generally, topomaps (which were prepared few years back) are used for terrain analysis, land use/land cover, road networks. Since the maps are very old, to compute and establish these influencing parameters, the existing methodology requires large amount of ground information/field work, which is time consuming, labour oriented.

Terrain modelling is carried out by generating DEM from topomap by digitizing contours. The height information is depends on the contour intervals. With the available topomaps twenty meter contour only possible if the relief is not high as Himalayas. In highly undulated terrain minimum forty meter contours are available form the map. So for better contour interval, extensive ground information is required.

As already discussed in chapter 3, IRS-1C PAN camera can be tilted to record stereo pair. Using the stereo pair data with sufficient stereo parallax and by applying suitable models, a terrain height profile or DEMs can be derived using these stereo pairs.

The IRS-1C/1D mission thus provide both planimetric and elevation information. The elevation information thus derived can be used in terrain correction of the images.

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DTM is a digital representation of sampled terrain that provides a measurement of elevation at specific ground co-ordinates. Along with location and elevation data for each site, DEM files will be organized to provide additional information that help to define the basic features of the database. Usually included with most DEM data is information about the specific DEM's boundaries, projection, maximum and minimum values and accuracy statistics.

4.7.1 DEM Generation

Basic inputs for DEM generation from the satellite stereo are (i) basic stereo pair containing the satellite image data and ephemeris and (ii) GCPs/Map. DEM generation contains four important steps,

(i) geometric modelling using photogrammetric collinearity conditions,
(ii) automatic/semi automatic conjugate point identification,
(iii) three dimensional ground co-ordinate determination of identified conjugate points and
(iv) height interpolation & DEM editing.

The software system developed by Space Applications Centre (B.Gopala Krishna, etc.).

(a) Data entry: All the necessary inputs required for initiating the DEM generation process are to be entered at this level, which include path, row, date of pass, satellite id, user corners etc., through a dialogue box.

(b) Data Downloading and Pre-processing: Image and ancillary data are downloaded under this task from the media in which raw data is stored. The user area is selected in terms of Sol map sheet extents with the help of Graphic User Interface (GUI), using corner co-ordinates of the basic stereo pair in the background.

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(c) GCP Collection: GCPs are collected through this task using a scanned map and the basic stereo pair imagery. GCPs are required for modelling the satellite orientation, which normally has certain uncertainty. A user friendly GUI helps in executing this task efficiently. The map is rectified first with respect to its tick marks, then using a projective transformation of the grid points; the ground coordinate of any other point (a GCP) on the map can be calculated. The elevation of the point is obtained from the elevation contours on map. Minimum four GCPs are to be identified, if more are there, they can be used as checkpoints in computing the model error later. If user has GCPs obtained from other sources, they can be entered manually through this task.

(d) Model Setup: The raw IRS-IC/ID scene suffers from a number of geometric distortions. These are due to the factors such as satellite orbit and attitude variations, sensor geometry, tilt angle, terrain relief etc. To correct distortions/orient the image a method of modelling the orbit and attitude parameters (Srivastava, 1989) of IRS-IC/ID has been developed using GCPs. The elliptic Keplarian orbit can be described by six independent parameters namely, semi major axis (a), eccentricity (e), angle of inclination (i), longitude of ascending node (\( \Omega \)), argument of perigee (\( \omega \)) and true anomaly (\( F \)). The initial values of these parameters are derived from the satellite ephemeris. Space resection refines these six parameters using modified collinearity condition equations, which state the perspective centre, image point and the corresponding ground point lie in a straight line at the time of imaging:

\[
(X, \ y, -\phi)^T = s.M \ (X_A\ X_S)
\]

Where \((x, y, -\phi)\) are the image co-ordinates of the GCP, \(s\) is the scale factor, \(X_A\) are the ground co-ordinates of the GCP and \(X_S\) are the perspective centre coordinates. \(M\) is the transformation matrix which is a function of tilt angle, attitude and orbit.

The major components of the dynamic motion are the earth's rotation and the satellite movement along the orbit path. These motions have been modelled as
linear angular changes of \( F \) and \( W \) with time as

\[
F = F_0 + F_t t \quad \text{and} \quad W = W_0 + W_t t.
\]

Assuming the effects of \( e \) and \( w \) are negligible, the parameters to be updated in the resection are \( F_0, F_t, W_0, W_t, e \) and \( i \). After executing model setup, updated orientation is created, which are used in the ground to image transformation. This task supports interactive selection of GCPs for modelling and takes the remained points as check points and gives the errors at each point in terms of easting, northing and height.

\( e \) Conjugate point Identification: This is an important step in DEM generation from satellite stereo pairs. The automatic/semiautomatic conjugate point identification developed and implemented in this package uses hierarchical matching technique based on an interest operator [Lu Yan, 1988] followed by an area based correlation. Hierarchical approach is selected to make the search area sizes (for correlation) very small at each pyramid of the hierarchy, to gain the computational advantage and to achieve more reliable correlation results. Interest operator selects candidate points for matching. The first pyramid starts on the reduced resolution image by a factor of 16. There are five pyramids in the hierarchy. At each pyramid, interest points are found out in one of the images (called reference image) and approximate co-ordinates for these points in the other image is found out through a local mapping (polynomial of order one) of previous levels match points (conjugate points). The procedure continues till it reaches the last level (original resolution). The number of points matched in the last level (level 1) is the final list of conjugate points. Provision exists to enter the conjugate points through the image display interactively up to level 4.

\( f \) Determination of 3D ground co-ordinates: Once the conjugate points are identified, the next task is to find out the DEM for these points. The co-ordinates of the points of interest can be computed in the object space using inverse
collinearity equation (IRS-1C Data Products 1993). Each image point in the overlapping images defines a ray from each image intersecting at an object point. Intersection of these rays coming from conjugate points determines the position of the point in object space.

(g) DEM Interpolation and Editing: Space intersection generates an irregular DEM at the conjugate points. In order to compute the heights at a regularly spaced interval, a height interpolation is to be performed. There are two options in this package (a) weighted average technique in which weights are calculated depending on the Euclidean distances of its neighbourhood points, and (b) Kriging method, uses variogram of the distances within a neighbourhood. After getting a regular grid of DEM, a median filter is applied to remove the spurious peaks of heights resulted due to the conjugate point mismatch during the correlation.

4.7.2 Terrain correction and product generation
Terrain correction and product generation basically involves five steps, (i) DEM generation using stereo pair and GCPs (ii) Model setup for updating the satellite orientation, (iii) geometric correction grid generation in polyconic map projection using ground to image mapping, (iv) resampling to generate a gray level image in a required output resolution.

The first two steps are described in previous section. The remaining processes are given below:

Grid Generation: The geometric correction grid for a given study area co-ordinates in a polyconic projection is prepared at a regular interval using ground to image mapping generated with collinearity condition equations and the updated satellite orientation. This transformation relates the input co-ordinates in one of the stereo/mono images corresponding to the geodetic input co-ordinates on the basis of satellite orientation parameters.
Resampling: Once the correction grid is generated, using the cubic convolution image resampling of the input image, corrected output gray level image is generated. Freedmann resampling algorithm is used. The co-ordinates within the grids are approximated using a bilinear transformation.

4.7.3 Uncertainty in Surface Models

The models used were tested extensively for the generation of DEM from stereo pair but in many cases it was difficult to separate the attributes of surface form that were due to geomorphological process from those due to model uncertainty. To distinguish the two sets of influences, the techniques suitable for identifying uncertain or inaccurate elements of surface models are discussed here. This is a necessary consideration and one that cannot be ignored if effective surface characterisation is to be achieved.

4.7.3.1 DEM uncertainty

The certainty with which we can assume a DEM represents true surface from is a function partly of the conceptual limitations of the model and partly the quality of the data provided. The methods of quantifying, visualizing and modelling DEM uncertainty are discussed here. (Wood 1993)

4.7.3.1.1 Quantifying DEM uncertainty

Several new descriptors as well as a description of uncertainty quantification methods commonly available are discussed here. They are presented in approximate order of completeness in their description. It is recognized that a compromise is sought between a concise and conveniently measured quantification and a comprehensive description. Hence some descriptions may not be applicable in all contexts. But all the methods described here are deals with the aspect of data quality.
4.7.3.1.1 Momental Descriptions

The conventional descriptions of a frequency distribution that include measures of central tendency and dispersion may be used to describe the pattern of deviation between two sets of elevation data. These measures are described as momental statistics (Miller and Kahn, 1982)

(i) Root Mean Square Error (RMSE)

The most widely used measure for reporting accuracy is the root mean squared error (RMSE) used by, for example, USGS (USGS, 1987). It is a dispersion measure, being approximately equivalent to the average (absolute) deviation between two datasets.

\[
RMSE = \sqrt{\frac{\sum (z_i - z_j)^2}{n}}
\]

Where \(z_i\) and \(z_j\) are two corresponding elevation values \(n\) is the number of elevation pairs modelled.

The difference between two sets of measurements of the same phenomenon is greater if the value of the Root Mean Square Error is large. It would be common therefore to use this as a quantification of the uncertainty of one or both sets of measurements. The most common use of the RMSE is to provide a single global measure of deviation. Consequently, there is no indication of spatial variation over the surface of the DEM.

As suggested by Guth (1992) and Carter (1989) the error can be positively spatially auto correlated. Non-random spatial variation in error cannot be revealed by a single aspatial measure. It is always desirable to separate the spatial trends from the non-spatial error component, when creating an error model (Goodchild, 1986; Heuvelink, 1993).
The RMSE has a dimension of [L], and is consequently usually measured in the same units as the original elevation data. This makes comparisons of RMSE values for areas with different relative relief values hazardous. The magnitude of the RMSE depends not only on our intuitive idea of error but on the variance of the true elevation distribution. This 'natural' variance will depend on relative relief, but also the spatial scale of measurements.

(ii) Accuracy Ratio
Relative relief effects from measurement deviation can be eliminated, by dividing RMSE by a measure of relative relief. This is most conveniently achieved by dividing by the standard deviation of elevation measurements.

\[ a = \frac{\sqrt{\frac{\sum (z_i - z_j)^2}{\sum (z_i - z_j)^2}}} \]

Where \( z_i \) and \( z_j \) are measured as above, \( z_i \) is the average elevation of \( i \).

(iii) Mean and Standard Deviation
These measures allow systematic deviations between values to be separated from symmetrical dispersion (Li, 1988, 1993a, 1993b; Monckton, 1994).

\[ d_{zij} = \frac{\sum Z_i - \sum Z_j}{n} \]

\[ s = \sqrt{\frac{\sum [(z_i - z_j) - d_{zij}]^2}{n}} \]
Where $z_i$ and $z_j$ are measured as above $dz_y$ is the mean deviation between models $s$ is the standard deviation between models.

Non-stationarity cannot be identified from these measures; a global trend may be measured as distinct from a more local error component. A non-zero mean value indicates that overestimates and underestimates of elevation are not equal, and that the overall accuracy of the model can be improved simply by subtracting the mean deviation from all elevation values.

(iv) Higher order moments
Measures of skewness and kurtosis have been used to characterise elevation distributions (Evans, 1979, 1980) and can be applied to the distribution of elevation model deviations.

\[
dz_y = \frac{\sum z_i - \sum z_j}{n}
\]

\[
skewness = \frac{\sum [(z_i - z_j) - \bar{dz}_y]^3}{ns^3}
\]

\[
kurtosis = \frac{\sum (z_i - z_j) - \bar{dz}_y]^4}{ns^4}
\]

These measures could provide a fuller description of the distribution of error while remaining parsimonious.

(v) Accuracy Histogram
In any form of data, a histogram (frequency distribution) provides distribution of data. In order to develop a reliable stochastic error model it is necessary to model the form of the accuracy distribution. If we regard model errors as independent random variables, the central limit theorem suggests distribution of those errors to be normal, with a mean of 0 and standard deviation $s$ defined as
above. In such cases, the distribution could be defined by a single RMSE value. However, as suggested above, this is unlikely to be the case for many elevation models. By comparing the modelled and actual frequency distribution of accuracy, it is possible to determine the degree to which error is successfully represented as an independent random variable.

4.7.3.1.1.2 Spatial Measures
Spatial patterning is another form of distribution of errors in elevation models. (Guth, 1992; Li, 1993a; Monckton, 1994). It is necessary to provide descriptions of the spatial pattern of error, to test this idea and build models upon it.

(I) Spatial Autocorrelation
It is possible to produce stochastic models of error that reflect to some degree, the spatial pattern of accuracy, by identifying the degree of clustering of error (Monckton, 1994). Moran’s I statistics (Cliff and Ord, 1981) which provides a convenient measure of the degree of spatial association between similar error values for measuring Spatial autocorrelation.

\[
I = \frac{n \sum_{u=1}^{n} \sum_{v=1}^{n} w_{uv} (d_{zu} - \bar{d}_{z})(d_{zv} - \bar{d}_{z})}{\sum_{u=1}^{n} (d_{zu} - \bar{d}_{z})^2 \sum_{u=1}^{n} \sum_{v=1}^{n} w_{uv}}
\]

Where \( d_{zu} \) is the deviation between the two models for each cell, \( d_{zv} \) is the deviation between the two models for some neighbouring cells, \( w_{uv} \) is the weighting given to neighbouring cells, \( d_{z} \) is the average deviation between the two models.

The statistic indicates clustering of values (approximately \( I=1 \)), random distribution (approximately \( I=0 \)) and local separation of similar values (approximately \( I=-1 \)). Exact limits are given in Goodchild (1986) and Bailey and
Gatrell (1995). It can be used in the generation of stochastic error models or in the examination of residuals from deterministic models.

(ii) Accuracy surface

In practice, it is rarely the case that two full and equivalent models of elevation are available for comparison. For such cases, two possible alternatives may be used each of which provides an estimate of the likely accuracy surface. If spot heights are available in addition to a DEM, the difference in elevation values may be found at spot height locations. Where there is some ambiguity between location and DEM cell boundary, a local planar or quadratic trend surface may be fitted through the local DEM cell neighbourhood. The value of this trend function can be calculated precisely at the spot height location. Once a series of accuracy values have been determined, it is useful to interpolate these over a continuous surface to aid visualisation and detection of trends (Wood, 1993). There are two major problems with this method, namely the representative selection of spot height locations and the arbitrary method of spatial interpolation. An alternative method of accuracy surface construction is available where the DEM is to be interpolated from source elevation data. By taking a series of selected samples from the source elevation data, a number of model realisations may be constructed. The variance in elevation between these models provides a measure of accuracy at all locations.

4.7.4 Evaluation and Testing the Model

The uncertainty in a DEM can have a profound effect on derived attributes such as slope and aspect. For this class of neighbourhood operations, the spatial autocorrelation of error becomes a crucial factor. Several studies have demonstrated that the error in the derived products decreases as the degree of spatial autocorrelation increases. Hence in this study, hybrid based approach was used to derive DEM, where two tier autocorrelation was done.
One of the most critical parts of the terrain corrected products generation is to evaluate the products. This includes both qualitative and quantitative aspects. DEM evaluation includes 1. checking of conjugate points, 2. checking of heights of known points like bench mark points, 3. the generated DEM manually/visually on the display monitor and 4. checking of modes using some check points. Errors in height calculation of GCPs, which are not included in model calculation, can give a very good estimate of model accuracy.

The study area contains different type's viz. flat region, medium undulations and moderate hilly terrain. The stereo pair also includes different tilt angles, resulting in B/H ratio of 0.68. The accuracy of the DEM and orthoimages are dependent on the source of GCPs. Better accuracies are achieved when GCPs are collected from 1:25,000 scale maps. DEM accuracies are not so good when the heights of the GCPs are obtained by interpolation of 40m interval height contours.

The DEM accuracy was checked at check points (RMSE) and found that for eight check points, the error at check points in Easting is 15.0 m and 14.0 m Northing and height accuracy is 12.5m.