Leveling of DEM Generated from Satellite Data for Mosaicking

Gaurav Vashisth, A. D. Prasad

Abstract— Digital Elevation Model finds use in wide range of applications. Often the study area in such applications is very large, which needs the mosaicking of the adjacent smaller DEM tiles. When adjacent DEMs are mosaicked together then systematic errors such as vertical offset and tilt between the DEM tiles can produce visible discontinuities along the borders of the overlapping areas. The standard mosaicking procedures reduces just the inconsistencies at the boundaries of the areas of overlap; the remaining portion of DEM tiles is left uncorrected. The method proposed in the paper uses the cell values present in the overlap region to reduce the vertical offsets and the tilt present in the DEM tiles so that they can be subsequently used for preparing mosaic of DEM tiles.

Index Terms—GIS, DEM, Leveling, Mosaic, Errors, Cartosat.

I. INTRODUCTION

DIGITAL Elevation model (DEM) is the representation of topographic and manmade features on earth's surface in digital form[5] . The term Digital Elevation Model is often used as a generic term for Digital Surface Models (DSM) and Digital Terrain Models (DTM), only representing height information without any further definition about the surface [8]. In the projects, like Rail/road alignment, hydrological modelling etc., where a very large area is under consideration, a DEM which can cover the whole area is required. One DEM tile generally does not cover the whole area, therefore different adjacent DEM tiles have to be mosaicked together to form a larger DEM. If the data is available in strips it can be treated as extended model and no mosaicking is required[3] . Aerial imagery data can be acquired in strips whereas Satellite data is not be available in strips. Therefore the different DEM tiles prepared from satellite imagery have to be mosaicked. Individual DEM tiles pose Orientation problem during mosaicing, as the stereo models are not adjusted to each other when control points have not been used for DEM extraction.

A. Mosaicking 3D Raster

The standard mosaicking procedures for 2 dimensional raster images does not work for mosaicking DEM raster images. Two overlapping DEM tiles may have different elevation values in the cells in the overlap region. These differences in elevations are due to the presence of systematic vertical and horizontal errors which produce visible discontinuities along the borders of the overlapping areas when mosaicking different DEM tiles [2]. The differences also include tilt and vertical offset [3].

By using the standard mosaicking procedures for the 2 dimensional raster images, the inconsistencies at the boundaries of the areas of overlap are reduced and provide results where discontinuities are no more clearly visible, but the systematic errors that caused the artefacts are not removed[2] as shown in figure 1. A method to estimate horizontal systematic error, in order to correctly co-registers the DEMs, and then to correct the systematic vertical and horizontal errors was developed in DUDES project funded by ESA [2]. Software tools have been developed to estimate the tilt and offset between individual DEMs and thus remove Orientation problems [4]. A single DEM for a large area (larger than a scene) by mosaicing scene based DEMs was generated and evaluation of the same using different techniques has been performed by using Cartosat 1 stereo pairs to prepare DEMs and ASTER DEM as a reference for the study [1]. It was found out that the distribution of accurate control points in the overlap area results in a uniform DEM in the overlap area. Also by generating tie points with only the RPCs and without control point's show that the accuracy can be further improved by giving highly accurate points as control points [1].

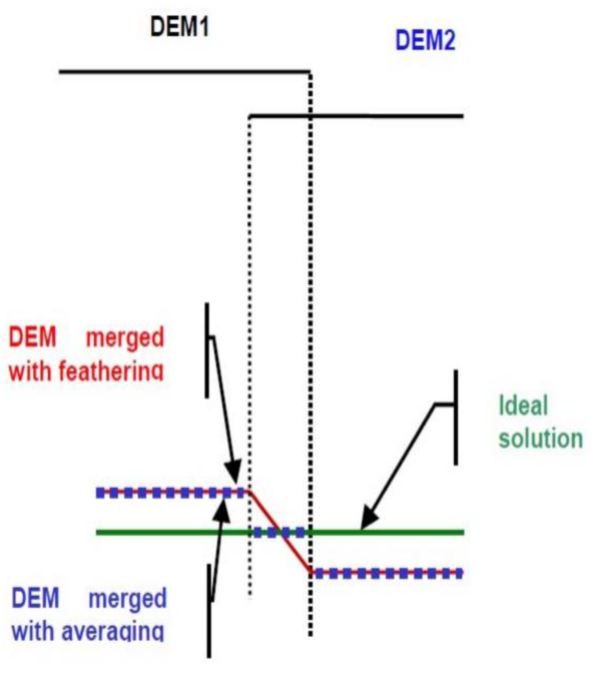

Fig. 1. Example of a mosaicking elevation error due to a vertical difference between DEM tiles.

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II. METHODOLOGY

A. Study Area

The study area comprises of Pathanamthitta, Kottayam, Kollam and Thiruanantapuram districts of State of Kerala, India. The study area falls in between 9°3'57'' N to 9°36'13 N and 76°38'59''E to 77°0'11''E. The area predominantly comprises of hills and valleys. The Western Ghats are on the eastern side and the western side comprises of coastal lowlands and midlands. The terrain on the whole is highly undulating. The general elevation of the area ranges approximately from 10m to 1000 m.

TABLE I
SPECIFICATIONS OF THE CARTOSAT 1

S.no	Parameter		Specification
1	Swath	Fore	29.42 km
		Aft	26.24 km
2	IGFOW	Fore	2.452 m (Across track)
		Aft	2.187 m (Across track)
3	Ground sample distance		2.54 m (Along Track)
4	Spectral band		0.5 – 0.85 microns

B. Input Data

Two pairs of Stereo images of Cartosat 1 imagery are used to prepare two Digital Elevation Models, the product used is Standard orthokitCartosat 1 product by ISRO. The Cartosat-1 satellite has two panchromatic cameras with 2.5 m spatial resolution, to acquire two images simultaneously, one forward looking (FORE) at +26 degrees and one AFT of the satellite at -5 degrees for near instantaneous stereo data. The specification of the Cartosat-1 imagery has been given in I. Ortho kit product supplied by NRSC comes with only radiometric corrections. They have location accuracy of 250m. A file consisting of the rational polynomial coefficients (RPC) is also provided for further processing at user's end. An orthokit product consists of an image file (GeoTIFF format), an RPC file (text file) and a metadata file [6]. The input imagery data is shown in figures 3 and 2. The two images from each stereopair are very similar in appearance, with the left scene appearing noticeably sharper.

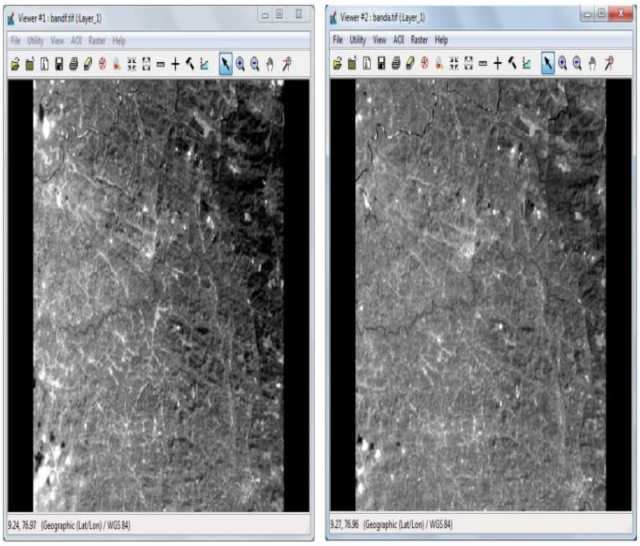

Fig. 2. Fore and Aft image of Stereopair 2

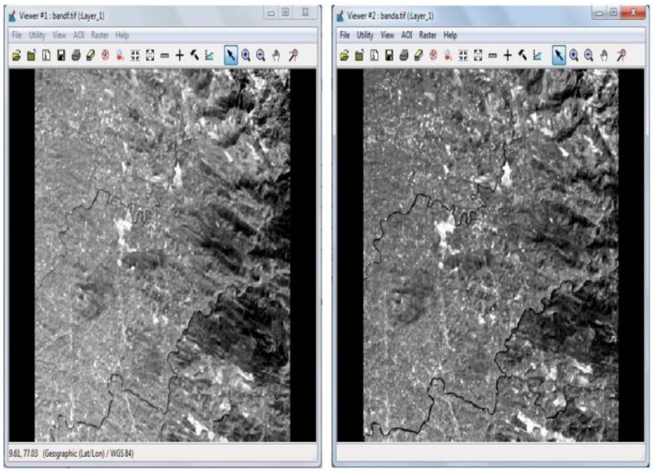

Fig. 3. Fore and Aft Image of Stereopair 1

TABLE II
CHARACTERISTICS OF THE INPUT STEREO PAIR TAKEN

Characteristics	Stereo Pair 1		Stereo Pair 2	
	Fore Image	Aft Image	Fore Image	Aft Image
Path & Row number	Path=0545 Row=0351		Path=0545 Row=0352	
Image Format	GeoTiff			
GenerationDateTime	09-NOV-08		19-FEB-10	
Resampling Code	Cubic Convolutions			

TABLE III
STRATEGY PARAMETERS FOR TIE POINT GENERATION

Parameter	Value Assigned	Comments
Search Size(pixels)	25 x 25	Increased because of large relief displacement in area.
Correlation Size(pixels)	4	Smaller value, reason same as above
Least squares size(pixels)	15	Smaller value recommended for large relief displacement.
Feature Point Density	100%	Default
Coefficient Limit	0.8	
Initial Accuracy	10%	Default

C. Software Tools Used

The various techonologies used incluce Java Programming language, ERDAS LPS, ArcGIS, Eclipse IDE for Java. Eclipse IDE was used as java environment, ERDAS LPS was used for DEM generation and ArcGIS was used for preparation of difference image, mosaicking of raster images and visualization of results.

D. Generation of DEM tiles

ERDAS LPS is used for the generation of DEM tiles. The process involved to generate each of the DEM is:

1) Cartosat RPC was used as camera model.
2) Automatic tie points were generated using the strategy parameters as given in III.
3) The positions of tie points were manually checked using the tie point measurement tool present in LPS.

4) Block Triangulation was performed using properties given in IV.

TABLE IV
PARAMETERS FOR DEM EXTRACTION

Output type	DEM
Output Form	Individual Files
Cell Size	X: 25 m Y: 25m
DEM Accuracy	5m
Horizontal Projection:	UTM
Horizontal Spheroid	WGS 84
Zone Number	43
Vertical Spheroid	WGS 84
Vertical Datum	WGS 84

E. Proposed Methodology

During the process of Methodology development, two solutions were thought off and coded for getting the results. Let them be called as Methodology 1 and Methodology 2.

1) Methodology 1 development: : Three common points in the two DEM tiles are used for calculating the translation and rotation parameters. The three common points in the two DEM tiles differ in their z values. These points are aligned with each other by translation and rotation. The same translation and rotations are applied on the whole DEM tile to level the DEMs.The Methodology1 developed is shown in figure 4 as flowchart.

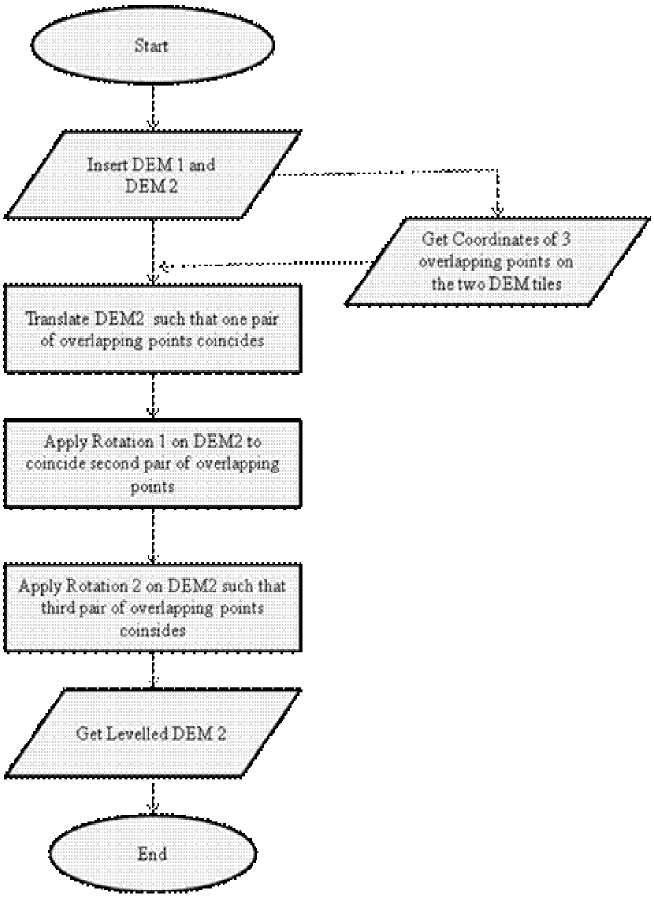

Fig. 4. Flowchart for Methodology 1

The methodology 1 is explained below.

1) Get the DEM 1 and DEM 2, DEM 1 would be used as reference and DEM 2 would be processed.

2) Get the coordinates of 3 points from the DEM 1 (which we assume as reference) falling in the overlap region.Get the z value of same points on DEM 2. It should be noted that their x and y component would be same but their z component would be different. Let us call the points on DEM 1 as DEM1-TP1, DEM1-TP2, DEM1-TP3 and the points on DEM 2 as DEM2-TP1, DEM2-TP2, and DEM2-TP3 as shown in figure 5.

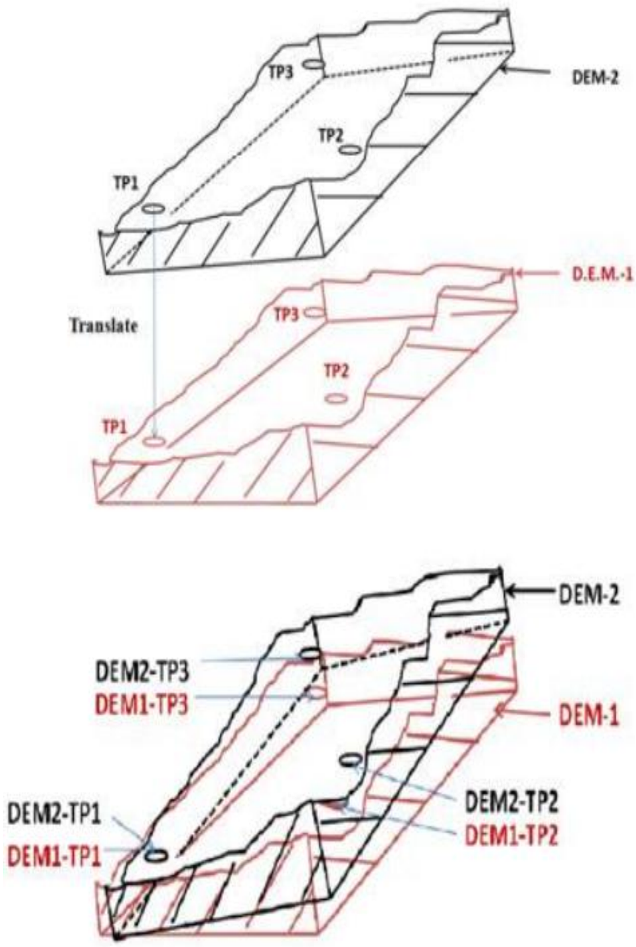

Fig. 5. Translation

3) Apply translation on DEM 2 such that one point on DEM 2-TP1 gets translated to DEM1-TP1 as shown in figure 5.

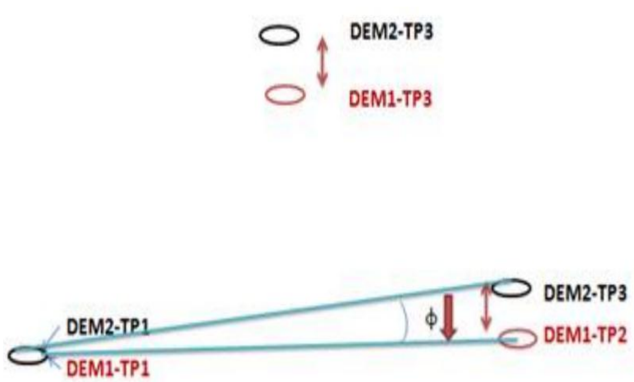

Fig. 6. Rotation 1

4) Rotation 1 on the resultant DEM 2 obtained from previous step. This rotation on the resultant DEM2 is performed as given in figure 6. The axis of rotation is y axis. . Let us

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call the first rotation angle as φ.

$$\varphi = \tan^{-1}\frac{DEM2TP2z - DEM1TP2z}{DEM1TP1x - DEM1TP2x} \quad (1)$$

where x and z denotes the x and z components of the points respectively.

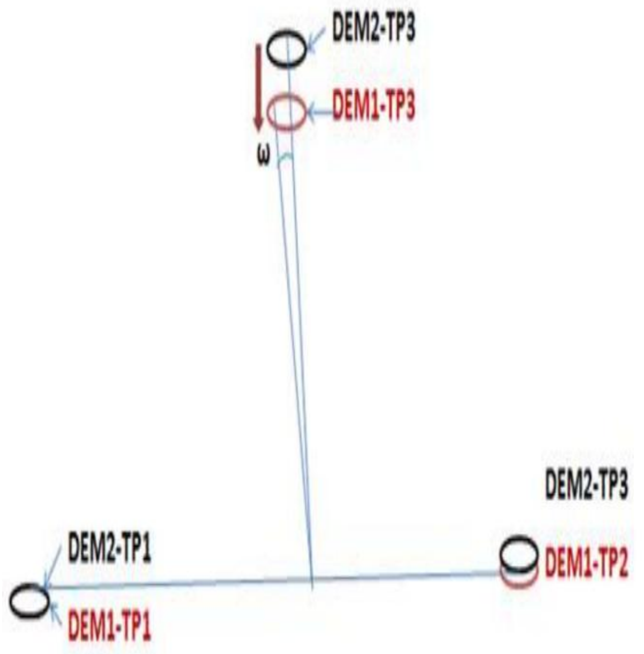

Fig. 7. Rotation 2

5) Again Rotation 2 on the resultant DEM2 as given in figure 7 is to be performed. The axis of rotation is the line joining DEM1-TP1 and DEM1-TP2.The angle of rotation 2 is denoted as θ.

$$\theta = \tan^{-1}\frac{DEM2TP3z - DEM1TP3z}{DEM1TP3x - D} \quad (2)$$

where D=distance of point DEM1TP3 from the line joining DEM1TP1 and DEM1TP2

2) Methodology 2 development: In the methodology 2 the three common points on the DEM tiles are used to calculate equations of two planes containing the corresponding points in the two DEM tiles. The rotation is performed according to the dihedral angle between the two planes. The methodology 2 developed is given in figure 8 in form of flowchart. Explanation of the methodology is given below.

1) Get DEM 1 and DEM 2.

2) Get the coordinates of 3 points from the DEM 1 (which we assume as reference) falling in the overlap area. Get the z value of same points on DEM 2. It should be noted that their x and y component would be same but their z component would be different. Let us call the points on DEM 1 as DEM1-TP1, DEM1-TP2, DEM1-TP3 and the points on DEM 2 as DEM2-TP1, DEM2-TP2, DEM2-TP3.

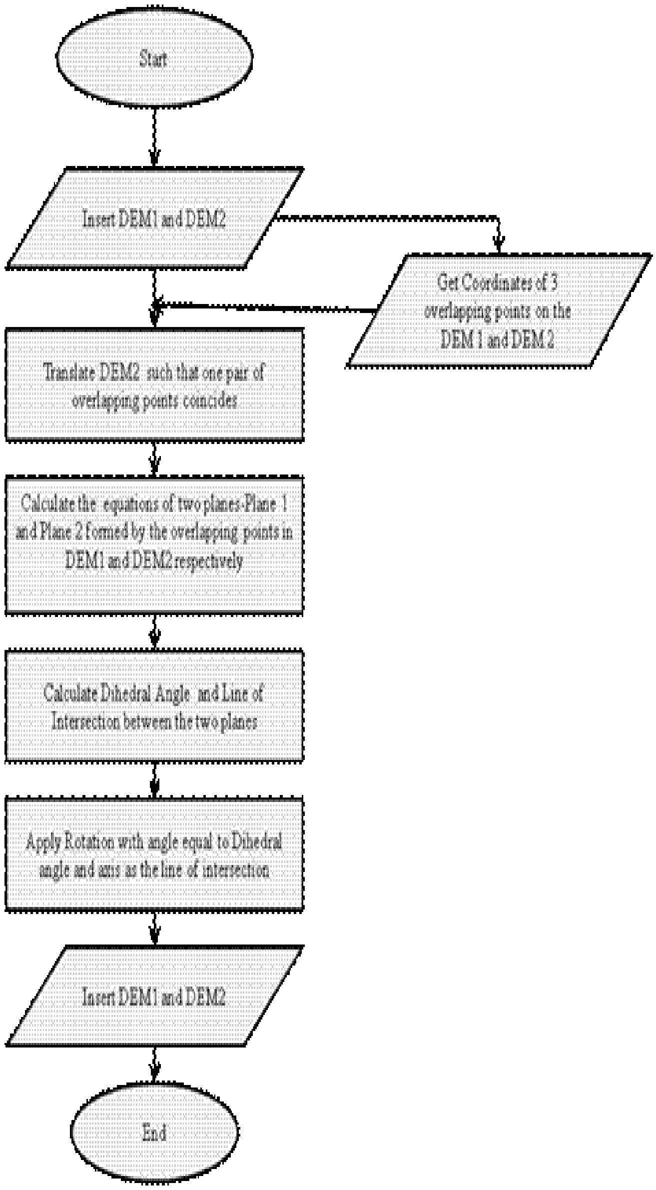

Fig. 8. Flowchart of methodology 2

3) Apply translation on DEM 2 The translation decreases the vertical offset between the DEM tiles.

4) Calculate the equation of plane 1 passing through the set of the three points for the DEM1-TP1, DEM1-TP2, DEM1-TP3 Also calculate plane 2 passing through set of three points DEM2-TP1, DEM2-TP2, DEM2-TP3.

5) Calculate the Dihedral angle between the two planes. Dihedral angle between two planes Ax + By + Cz + D =0 and A‘x + B‘y+ C‘z+D‘=0 is given by

$$\cos\theta = \frac{AA' + BB' + CC'}{\sqrt{A^2 + B^2 + C^2}\sqrt{A'^2 + B'^2 + C'^2}} \quad (3)$$

6) Calculate the line of intersection between the two planes. The line of intersection would act as axis of rotation for subsequent rotation.

7) Apply rotation on DEM2 with axis of rotation as the line of intersection calculated in the previous step, and angle of rotation as dihedral angle calculated in the preceding step.

3) Modified methodology 2: To accommodate more than 3

points for the calculation of planes, methodology 2 is modified. The flowchart for the methodology is given in figure 9. The modification in methodology 2 is that here best fit plane is calculated. For calculating the equation of best fit plane which passes through more than 3 points principal component analysis is used [7]. The x, y and z values of the points taken are used as variables to compute principal components. Principal Components Analysis can be used to fit a linear regression that minimizes the perpendicular distances from the data to the fitted model. This is the linear case of what is known as Orthogonal Regression or Total Least Squares, the distance of points from the fitted plane is minimized with respect to all the three points. Coefficients of 1st two Principal Components define vectors that form the basis of the plane. The third Principal Component define the normal vector of the plane as it is orthogonal to the first two components

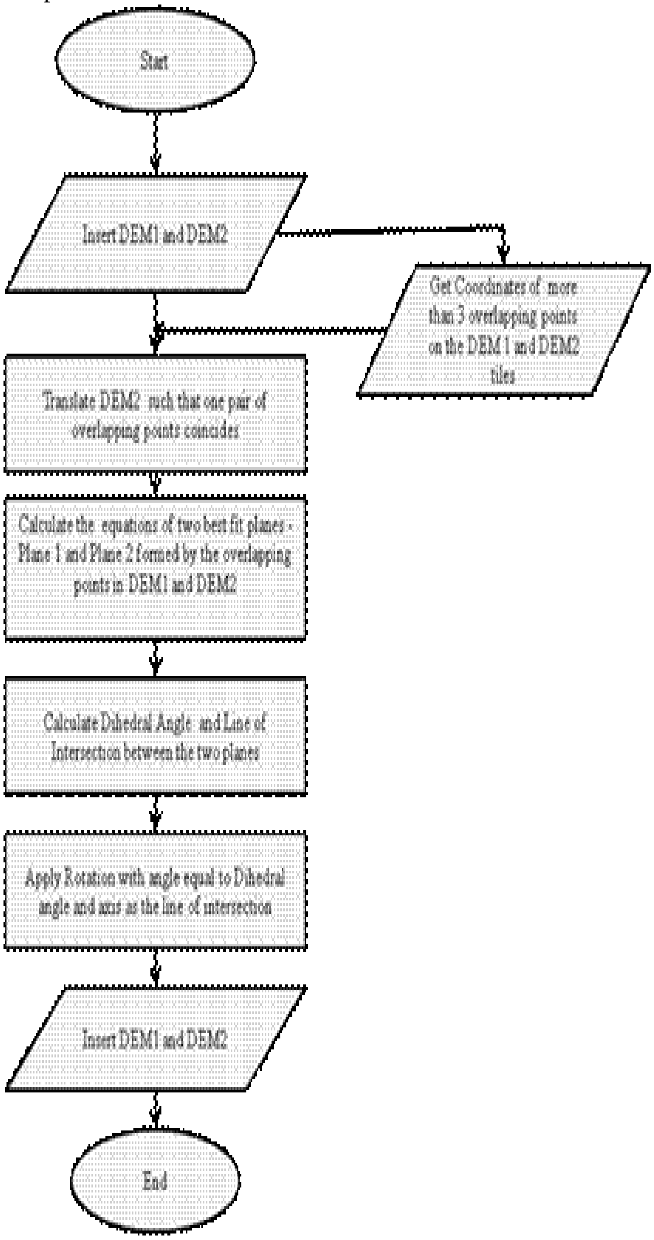

Fig. 9. Modified methodology 2

4) Processing the DEM tiles with the tool developed: The methods discussed in the preceding sections are used to develop a software tool. The tool developed is used to correct the tilt and vertical offset in the DEM tiles. The Methodologies are used on the DEMs and the results are analysed. Different sets of common points are used to get the results to find out the best way to level the DEMs for mosaics. To analyse the results a difference image between the two DEMs is created. At last the resultant DEM tiles from the experiments are mosaicked with the help of mosaic tool in ArcGIS.

III. RESULTS AND ANALYSIS

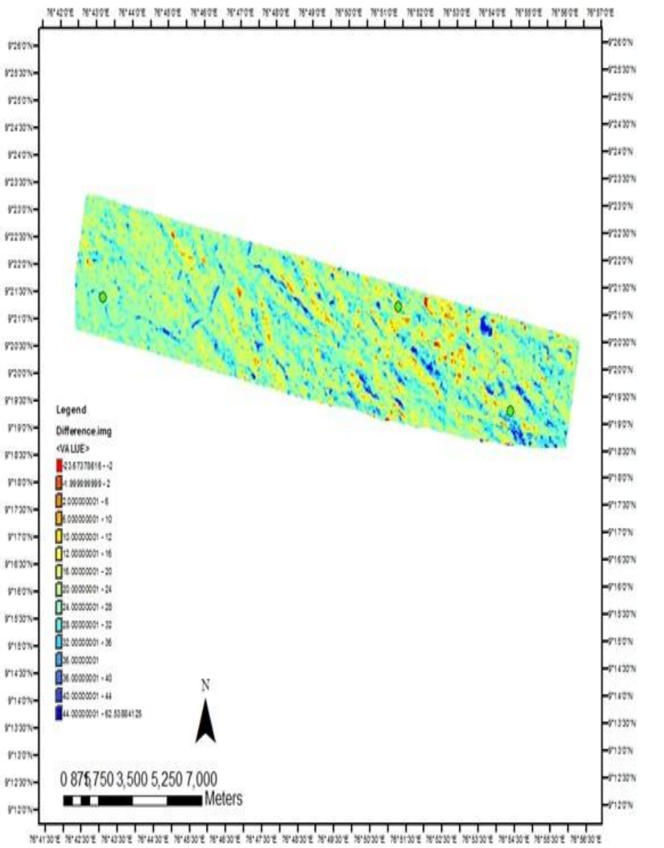

Fig. 10. Difference image between the original input DEM tiles

Figure 10 shows the difference image between the original input DEM Tiles. On observing the Difference Image,

- It is seen that most of the pixel values show large value i.e. more than 20 meters.
- As the difference image is made by subtracting DEM 2 from DEM 1 , the positive values shows that DEM 1 is in general above the DEM 2.
- Areas of low pixels value have a very low frequency of occurrences and are scattered in the Middle East part of the image. It indicates tilt in the DEM tiles.
- The Mean difference is observed as 23.48 m with a standard deviation of 7.03 m.

Thus we see that the elevation difference between the two DEMs is very large. It shows that the two DEMs are not oriented with each other. Mosaicking the two DEMs together with the available mosaic operators (such as mean, maximum, minimum, first, last etc) would only change the elevation values at the overlap area and not the whole DEM. Therefore to mosaic the DEMs together there is a need to level one DEM with respect to the other by using the methods discussed. The solution in which the pixels of

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the difference image of the DEMs approach zero is the better one. Various experiments were conducted some of which are documented in tabular form in V. The difference images recorded from the experiments are given in figure 11.

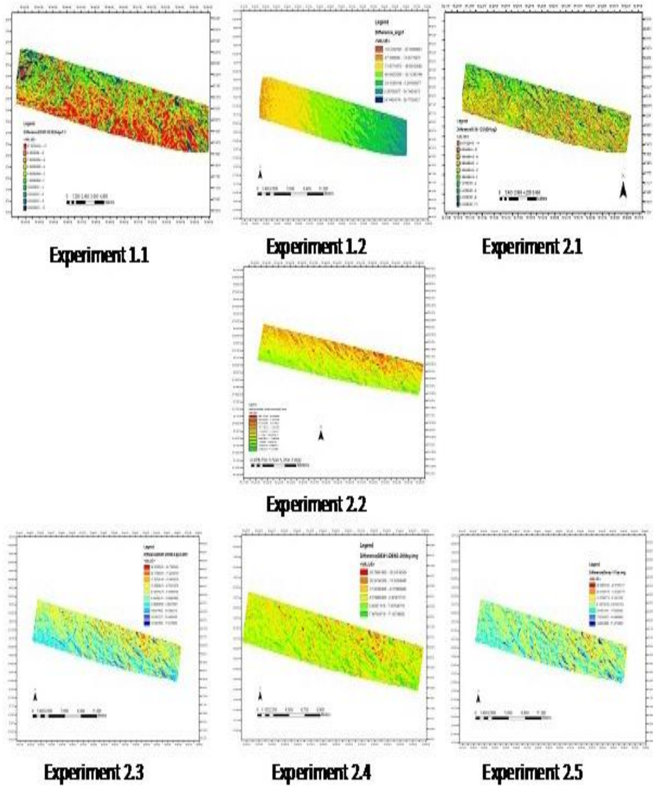

Fig. 11. Result Difference images of the Experiments conducted

TABLE V

EXPERIMENTS PERFORMED AND THEIR RESULTS

Experiment	Methodology used	Common points used	Mean of Difference Image (m)	Standard Deviation of Difference Image (m)
1.1	1	1, 2, 3	-6.93	7.26
1.2	1	4, 5, 6	-35.86	24.85
2.1	2	1, 2, 3	-4.94	7.28
2.2	2	4, 5, 6	-6.32	8.98
2.3	2	4, 6, 11	-4.54	7.34
2.4	2(modified)	1 to 6	-2.79	6.98
2.5	2(modified)	1 to 11	-2.37	6.94

A. Results from experiments in Terms of Difference Images

Experiment 1.1 gives a difference image with mean -6.93 m, thus it is seen that the mean difference has decreased by a large amount (from 23.48 m to -6.93 m).The difference image shows there is still tilt as most of cell values in the southern part is lower than the northern part.

Experiment 1.2 gives a difference image with mean -35.86 m which means that the mean difference has increased (from 23.48 m).The difference image shows presence of a large tilt as cell values in eastern part are highly positive whereas the cell values in the western part are highly negative.

Experiment 2.1 gives a difference image with mean -4.94 m, thus the mean difference is decreased by a large amount (from 23.48 m to -4.94 m).The difference image does not show presence of tilt as there is no pattern of cell values as was present in previous experiments. Experiment 2.2 gives a difference image with mean -6.32 m, thus mean difference has decreased by a large amount (from 23.48 m to -6.32 m).The difference image does show presence of tilt as a pattern of cell values can be observed, the cell values in the southern part are positive whereas the cell values in northern part are negative. Experiment 2.3.results in difference image with mean –4.54 m, thus we see that the mean difference is decreased by a large amount (from 23.48 m to -4.54 m). Uniform cell values are oberved. But still the cells in the on the northern eastern direction have negative values whereas the pixels on the southern side have mostly positive values. In the experiment 2.4, in which 6 points are used, the mean observed is -2.8 m which is the lowest recorded when compared to the previous experiments. The difference image shows fairly uniform cells values in most of the plane. Extreme values are found in the hilly region in the North Eastern part and in the course of the river in western part. In the experiment 2.5, where 11 points are used, the mean observed is -2.37 m which is the best so far. The difference image shows fairy uniform cell values when compared with difference images recorded in previous experiments. Extreme values are found in the hilly terrain in the North Eastern part and along the course of the river in the western part.

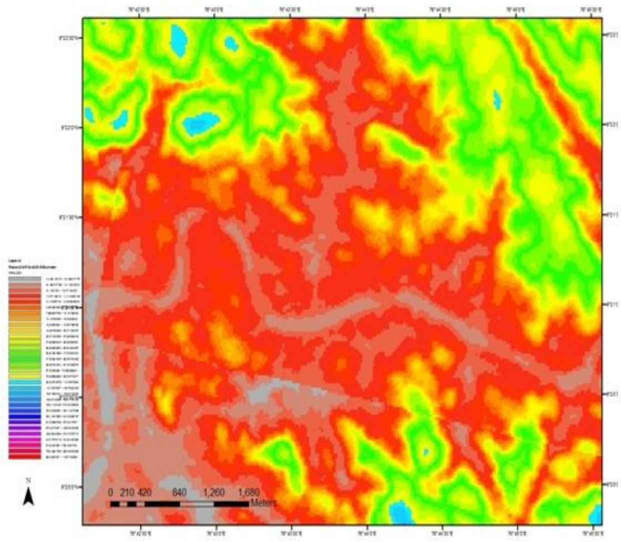

Fig. 12. Discontinuity in the overlap boundary in mosaic of DEM 1 and DEM 2

B. Mosaicking of DEM tiles

The images are mosaicked using the mosaic tool in ArcGIS. 12shows the mosaic of DEM tiles before the processing, the method used for mosaicking was ‘mean’. 13 shows the DEM mosaic which is prepared by using the result DEM tiles from Experiment 2.5. It is found out that the discontinuities have been removed from the mosaic

C. Analysis of results

From the V it is inferred that using the Methodology 2 would give better solution compared to the Methodology 1. Also the modified methodology give better results, where more than 3 common points are used then. Extreme values in the difference images are found to be present in the same locations in all the difference images. Figure 11 shows the cell values which are in the extreme end of _ + _overlaid over the ortho image prepared from the Cartosat image using the DEM. It reveals that the extreme values are present in the locations where there is abrupt change of elevation and in the course of the river. The western (relatively flat) region has very low occurrence of extreme difference values. The presence of extreme values may be due to failure during the correlation process while calculating the stereo model. Another reason may be the extreme values are due to presence of horizontal offset between the two DEMs. The methodologies applied on the DEM are helpful in levelling one DEM with respect to the other. Using these methodologies before going for the mosaicking would certainly give better results. The quality of the resultant DEM is varying with the chosen common points, common points must be chosen in such a way that those points must not contain any other error. The difference in the produced in the DEM mosaic could be easily evaluated visually in figure 12 and 13.Figure 12, showing original DEM mosaic has visible discontinuity, whereas Figure 13, showing DEM mosaic with the methodology described has no such discontinuity.

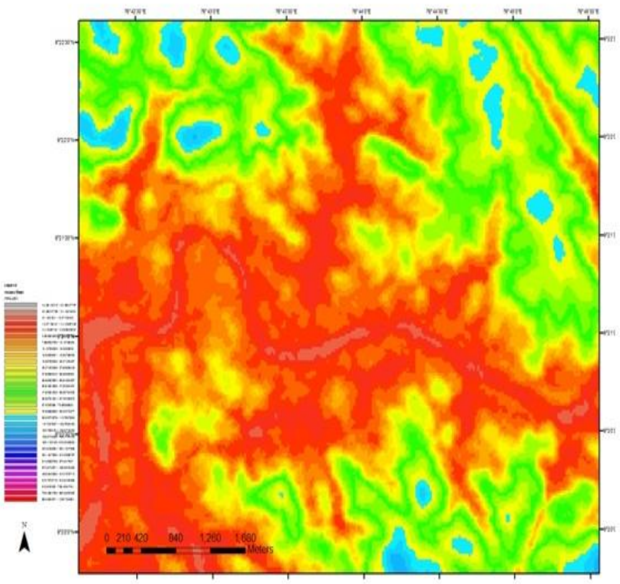

Fig. 13. Discontinuity removed after using the methodology described

IV. CONCLUSION

Different methodologies were used to level the DEM for mosaicking. The first method, where 3 common points are used (whose x and y coordinates are same) and translation followed by two rotations is used, did decrease the elevation difference in the overlap region sometimes but it is much dependent on the choice of the common points taken. In the second method, 3 common points were taken from each of the DEM image, and two planes containing the respective common points from each DEM were calculated. Dihedral angle and line of intersection between the two calculated planes was then found out. The second DEM was then rotated at an angle equal to dihedral angle with line of intersection equal to axis of rotation. This method gave far better results than the previous methodology used. Still the difference between the two DEM tiles in the overlap region depended on the choice of common points used. The second method was then modified to accommodate more than 3 common points. A best fit plane was calculated for the common points in each DEM. This method gave the best results when compared with the previous two methodologies. As per the results found, it may be said that adjacent DEM tiles can be levelled with each other by using this method and a DEM strip can be formed. The average elevation difference between the two overlapping DEM tiles has been decreased by a vast amount using the methods discussed in the Paper. This method can also be helpful in control extension if one of the DEM tile is absolutely oriented with the help of ground control points. Also it was observed that in the hilly regions the elevation values observed by the tow DEMs were having very large contrast. The reason behind such difference has to be studied and modelled.

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