Production of DTM by using the existing contour data lines

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Abstract

The topographic database in Nepal has been prepared in the national level by making use of the analogue topographic base data. Topographic dynamics in terms of other physical features changes rapidly but changes in the terrain elevation occurs negligibly. As there has been growing demand for digital height model (DHM) of the terrain in spite of the presence of the existing two and half dimensional data such as contours, work was done as to the input, methodology, and quality assessment of the DTM being generated on the national level. Some initiations taken in this respect has been highlighted in this paper.

Introduction

Digital Height Models (DHMs) or Digital Elevation Model (DEM) or synonymously Digital Terrain Model (DTMs) are computer models of the surface of the Earth and are being increasingly used by scientists from many disciplines for tasks such as estimating slope gradient and aspect to operations such as analysing the hydrological flow paths on the surface. Targeting the generation of hydrologically precise DTM may lead the product to be used in the wider domain than to produce it for other use since the former takes account of the majority of the curvature of the surface than mere interpolation of the input points.

Making the national level DTM database in the country like Nepal, where the terrain varies from the level as close as to 68 meters to the peak of Mount Everest of 8848 meters is a difficult task. Lack of the photogrammetric workstation for automatic digital terrain model extraction and at the same time absence of the spot levels in the required amount heightens the problem of the DTM creation by the stereo modelling procedures or point interpolation methods.

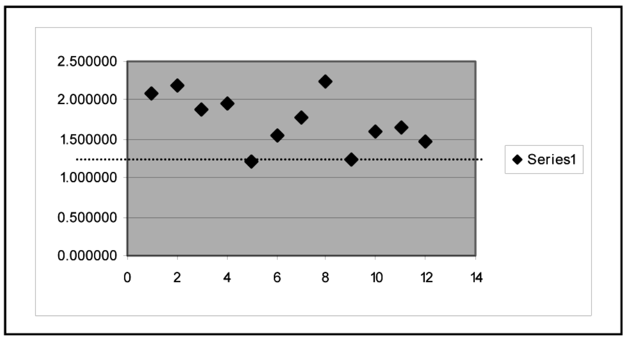
In this scenario, to consider the users' demand and at the same time to enhance the scope of framework data in the user community, a long awaited DEM is being prepared by making use of the topographic linear vector data as the major source of relief. DEM is one of the basic dataset that a general user requires. Survey Department being the National Mapping Organization, it is desirable that DEM is replaced along with NTDB. But lack of essential tools along with other technical constraints, it could not be generated at the time of release of NTDB. Presently as there is presence of tool in Geographic Information System that accepts the vector contour line data along with other break line features such as boundary and the hydro lines as inputs, it is worthy to prepare the DTM by making use of such tool in the map sheet level. Accuracy assessments are made for deciding which map-sheet DTMs are acceptable to use. Such assessment is carried out against the accepted standards.

Basis for the map sheet selection

Majority of the area falls in the mountainous region in Nepal causing majority of the map sheets of 1:25000 and all of 1:50000 to cover the elevated terrain. Out of 678 unique map sheets for the whole country, around 400 sheets cover mountainous areas. Visual inspection of these map sheets shows that most of them contains high contours density. 12-map sheets were sampled consisting of semi plain or mountain areas. Contour line density (CLD) per square meters is calculated by measuring the contour vertices within the double of the pixel area size. The statistics of the CLD calculated as the ratio of the mean to the standard error was plotted. Map sheet visually estimated to be inappropriate for the generation of DHM were found to be located at the lower position whereas those with mean higher contour density with low Standard Error were plotted at higher position.

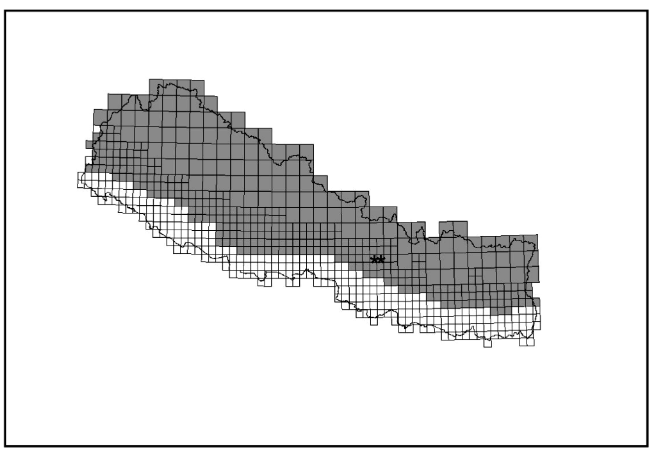
With the scatter diagram a threshold value of the ratio for the acceptance of the contour map sheet to use for DHM generation was set as 1.25 setting the rule that the sheet bearing the value greater than 1.25 will be used for the DTM generation. The following table shows the distribution list of the measured CLD values.

SN	Sheet Number	Min	Max	Mean	St. Deviation	Mean/St.Dev.	Remarks
1	2687 03C	0	0.08437	0.02838	0.0135660	2.091847	Eastern Chure Area
2	2687 03D	0	0.12388	0.03031	0.0138990	2.180589	Eastern Chure Area
3	2687 04C	0	0.08798	0.02453	0.0129990	1.887299	Eastern Chure Area
4	2785 09B	0	0.16760	0.03050	0.0156380	1.950058	Central Chure Area
5	2785 09A	0	0.11301	0.02082	0.0170260	1.222601	Central Chure Area
6	2883 16B	0	0.09426	0.02011	0.0130070	1.546244	Central Mountain
7	2782 03A	0	0.01506	0.02133	0.0119080	1.790897	Central Chure Area
8	2882 15C	0	0.09402	0.02907	0.0129720	2.240595	Central Chure Area
9	2884 13A	0	0.11701	0.01718	0.0139170	1.234677	Central Mountain
10	2884 14D	0	0.12018	0.01864	0.0116680	1.597189	Central Mountain
11	2881413C	0	0.09233	0.02339	0.0142770	1.638579	Central Mountain
12	2785 09D	0	0.08387	0.01872	0.0127884	1.463983	Central Meridian



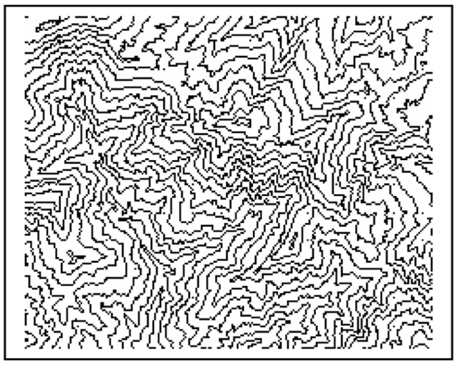
Visually observed with the contour line distribution with reference to the above sample possibly indicate the sheet layout to be used for DHM as follows (Gray shaded sheet to be used for DTM, counting to 400).

The above plot indicates that out of the 12 sampled sheets, sheet no. 5 and 9 shows values less than 1.25, which are the topo sheet number 2785 09A and 2884 13A. The highest value is from the sheet number 8, which is 2.24 approx. the topo sheet number being 2882 15C. Generalized hundred meters contour interval appearance of such map sheets has been given in the following page.

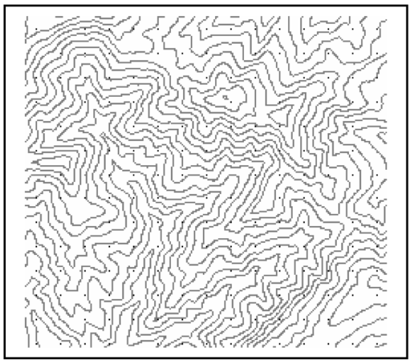


* Sheets having partially adequate contour density such as 2785 06A, 06B are ignored in the DTM Generation

(Source: Survey Department)



(Original Contour lines in the interval of 100 meters)



(Generalized Contour data in the interval of 100 meters using the DTM generalization techniques)

Methodology

The approach used in generating the DHM is the interpolation of contour line data. Contours from the map sheets are used as the main source of the input data. The output will be the raster in ESRI grid format of 10-meter spatial resolution. The tools used in the generation of the DHM are the interpolation tools of ArcGIS "Topo to Raster". Topo To Raster is an interpolation method specifically designed for the creation of hydrologically correct digital elevation models (DEMs). It is based upon the ANUDEM program developed by Michael Hutchinson (1988, 1989).

The interpolation process

The interpolation procedure has been designed to take advantage of the types of input data commonly available such as contours, stream ordered hydro features as the known characteristics of elevation surfaces. This method uses an iterative finite difference interpolation technique.

It is optimized to have the computational efficiency of local interpolation methods such as Inverse Distance Weighted interpolation, without losing the surface continuity of global interpolation methods such as Kriging and Spline. It is essentially a discretised thin plate spline technique, where the roughness penalty has been modified to allow the fitted DEM to follow abrupt changes in terrain, such as streams and ridges (Wahba, 1990). It is the ArcGIS interpolator designed to work with contour inputs. (www.esri.com)

Most landscapes have many hill tops (local maximums) and few sinks (local minimums), resulting in a connected drainage pattern. Topo to Raster uses this knowledge about surfaces and imposes constraints on the interpolation process that results in connected drainage structure and correct representation of ridges and streams. This imposed drainage condition produces higher accuracy surfaces with less input data. The quantity of input data can be up to an order of magnitude less than normally required to adequately describe a surface with digitized contours, further minimizing the expense of obtaining reliable DEMs.

The program acts conservatively in removing sinks and will not impose the drainage conditions in locations that would contradict the input elevation data. Such locations normally appear in the diagnostic file as sinks. This information is correct data errors, particularly when processing large data sets. (www.esri.com)

Quality assessment

Data without indication of their quality are almost as worthless as no data at all. Is a given DHM good enough for my application? : A question every DTM user asks. Contour lines for topographic maps are usually plotted under the criterion. E.g. 90% of the checked value should be in error by more than half the contour interval.

(a) Part of a DTM generated from contour lines (Source: Survey Department)

(b) Hillshade of Part of (a)

All DEM's data grid will be tested with reference to the spot height points generated photogrammetrically and those exist on the topo sheets. Corresponding vertical RMSE for each sheet will be specified in a header text file and will be delivered along with the DEM data to the user. It is proposed that the Meta data pertaining to the DEM will be launched via the NGII platform

Because of practical limitations inherent in all collection systems (DEM source data are always treated as a sample data) there will always be some artifacts such as patches, or some other anomaly in the data set. Some of these artifacts, although falling within normal DEM vertical error tolerances, can coalesce with valid surface features. This coalescence should not be tolerated to the point where valid surfaces become unintelligible to the users of the data (Specifications, Standard for Digital Elevation Model, USGS). For example:

- Isolated tops must be depicted with their approximate size and shape.
- Flat trending surfaces must be depicted as generally flat trending without confusing patterns or striations.
- Water bodies must be flat, be lower than the surrounding terrain, and have shorelines clearly delineated.

Corrective actions have been taken to minimize these artifacts; all DEM's must be viewed and edited before being submitted to the NTDB.

It is quite common to use as an accuracy measure the root mean square error (RMSE). The root mean square indicates the error we can expect on an average when computing elevation at an arbitrary point. The most widely applied method to assess the accuracy of a DTM is to compare elevation computed from the DTM with check values at randomly distributed points and to calculate the RMSE.

Coming to the point, for our task, the checkpoints were taken as the spot elevation point vectors from the NTDB, which were not used in the DHM generation themselves. Spot elevation from the two map sheets namely, 2785 11A and 2785 09D (both of which are within the threshold for the map sheet selection) were used. Excluding the spot heights, which are positioned wrongly, the RMSE were observed as 5.81 and 6.68, which are inside the tolerance of 7 m. In either case around 80% of the points are with in the half of the counter interval.

The DTM generated using the TIN data model gave the standard error of 6.63 for the sheet of 2785 11A and 9.31 for the sheet of 2785 09D. Comparing to this result, it can be said the DTM produced by using interpolation of the contour lines is of better accuracy than the same produced using the TIN data model. The points used in the calculation for the sheet of 2785 11A and the related parameters of the products has been attached in the appendix of this paper.

The tables below shows some parametric values of the analysis.

Sheet Number	RMSE wrt Tin	RMSE wrt DEM
2785 09D	9.31	6.68
2785 11A	6.63	5.51
2786 16 **B**	8.54	5.92

Specifications

Specifications for the DEM includes its structure, format, resolution, projection and coordinate system. Prior to the DEM data generation by Survey Department, study had been carried out to the specification standard of the DEM produced by USGS. The following are the standards of the DEM produced by Survey Department.

Terms	DEM by Survey Department	DEM by USGS (LEVEL 1)
1. Storage Format	ESRI GRID	ASCII Characters
2. Spacing (Spatial resolution)	10 meters	30 meters
3. Acquisition Methodology	"Topo to Raster Interpolation tool" using contour data as the primary source	Stereo Profiling or image correlation
4. Spatial domain of availability	7.5' or 15' (coordinates of extent depending upon the topo map sheet)	7.5'
5. Vertical Accuracy	80% of the tested points within half of the contour interval (10 meter)	7 meters RMSE but maximum RMS error 15 meters
6. Absolute Error tolerance	v25 meters	50 meters (w. r. t. true elevation)
7. Coordinate system	Rectangular	Rectangular
8. Projection	MUTM	UTM
9. Ellipsoid	Everest 1830 (Nepal Standard)	NAD

Use of DTM

DTM is used in the following fields of application.

- Hydrological modeling and estimation of run off.
- Ground water modeling
- Flood Hazard modeling.
- Urban Planning
- Real visualization of surface
- Agro pocket area findings.
- Forestry and Road alignment
- Study of Geomorphology
- Irrigation and Hydropower
- Erosion Hazard modeling
- Defense Mapping
- Marketing and Business analysis
- Mapping of Obstacle Clearance Surface for Approach and Departure of Airplanes
- Mapping and Maps updating etc.

Conclusion

DTM is an important source of spatial information which form an important data layer in the NTDB. NTDB in any country must have a dataset regarding DTM which can be applied seamlessly in one's spatially related analysis. The existing infrastructure does not permit to model terrain surface for the whole country (except the mountain or higher mountain areas) it is recommended to develop digital photogrammetric system for generation of automatic digital terrain model extraction for the remaining flat areas. The generated DTM using the counter lines as the primary input in the mountainous areas is not the completion but the beginning of developing 3d dataset in Nepal. More research and study is required for further findings as to the corrections pertaining to the roughness of the surface, smoothing mechanism of the data etc.

References

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Bishwa Acharya, Ph.D.; Jeffrey Fagerman, RLS; and Clarence Wright, Accuracy Assessment of DTM data: A Cost Effective Approach for a Large Scale Digital Mapping Project, IAPRS, Vol. XXXIII, Amsterdam, 2000

Karel, Pfeifer, Briese -DTM Quality Assessment

USGS, Standard for Digital Elevation Models

Appendix for the observed spot points for the error calculation

2785 11A

ID	SEL	NEW_HGT	TOPOG_PT_	TOPOG_PT_I	FCODE	SEL	TINZ	DELTINZ	NEW_DELZ
1	2395	2387.39	1	0	20400	2395	2380.00	15.00	7.61
2	2029	2026.23	2	1	20400	2029	2020.00	9.00	2.77
3	1463	1459.98	3	2	20400	1463	1460.00	3.00	3.02
4	1482	1487.61	4	3	20400	1482	1480.00	2.00	-5.61
6	2542	2545.93	6	5	20400	2542	2540.00	2.00	-3.93
7	1895	1888.09	7	6	20400	1895	1880.00	15.00	6.91
8	2533	2524.69	8	7	20400	2533	2520.00	13.00	8.31
9	2284	2283.10	9	8	20400	2284	2280.00	4.00	0.90
10	2702	2701.63	10	9	20400	2702	2700.00	2.00	0.37
11	2709	2708.81	11	10	20400	2709	2700.00	9.00	0.19
12	2805	2805.40	12	11	20400	2805	2800.00	5.00	-0.40
13	2567	2566.94	13	12	20400	2567	2560.00	7.00	0.06
14	2768	2765.20	14	13	20400	2768	2760.00	8.00	2.80
15	2551	2546.33	15	14	20400	2551	2540.00	11.00	4.67
16	1846	1841.20	16	15	20400	1846	1840.00	6.00	4.80
17	2306	2307.10	17	16	20400	2306	2300.00	6.00	-1.10
18	2290	2283.74	18	17	20400	2290	2280.00	10.00	6.26
19	2695	2686.90	19	18	20400	2695	2680.00	15.00	8.10
20	2327	2330.77	20	19	20400	2327	2321.25	5.75	-3.77
23	2064	2058.96	23	22	20400	2064	2060.00	4.00	5.04
24	2101	2102.09	24	23	20400	2101	2100.00	1.00	-1.09
25	2529	2522.24	25	24	20400	2529	2520.00	9.00	6.76
26	2769	2765.60	26	25	20400	2769	2760.00	9.00	3.40
27	1852	1854.08	27	26	20400	1852	1847.54	4.46	-2.08
28	2585	2581.68	28	27	20400	2585	2580.00	5.00	3.32
29	2515	2509.51	29	28	20400	2515	2500.00	15.00	5.49
31	2108	2107.35	31	30	20400	2108	2100.00	8.00	0.65
32	2615	2609.23	32	31	20400	2615	2600.00	15.00	5.77
33	2502	2502.74	33	32	20400	2502	2500.00	2.00	-0.74
35	2612	2602.97	35	34	20400	2612	2600.00	12.00	9.03
36	1635	1625.02	36	35	20400	1635	1625.24	9.76	9.98
37	2583	2581.59	37	36	20400	2583	2580.00	3.00	1.41

(Source: Survey Department)