DEM Registration and Error Analysis using ASCII Values

Suma Dawn, Vikas Saxena, and Bhu Dev Sharma

***Abstract*—Digital Elevation Model (DEM), a representation of the ground topology, is heavily used in many applications including construction modeling, visualization, and GIS. Their registration techniques are minimal have not been explored much. Methods like Coarse-to-fine or pyramid making are common in DEM-to-image or DEM-to-map registration but haven't been used much or DEM-to-DEM registration. Self-consistency measure used to detect any change in terrain elevation was used for the above mentioned. But these methods, apart from being time and complexity intensive, lack in error matrix evaluation. This paper gives a method of registration of DEMs using specified height values as control points by initially converting these DEMs to ASCII files. Here, these control points have been found by two ways - either by direct detection of appropriate height data in ASCII files or by edge matching along congruous quadrangle of the control point, followed by sub-graph matching. Error analysis for the same has also been done.**

***Index Terms*—Digital Elevation Model (DEM), Edge matching, Self-consistency, Error Analysis**

I. Introduction

DEM (Digital Elevation Models) are data files that contain the elevation of the terrain over a specified area, providing the "Bare Earth" look [42], [43]. It epitomizes the elevation attribute of the terrain in discreet form in a 3-D space of a surface [1]. These height values are depicted as grid points and the intervals between each of the grid points is referred to some geographical coordinate system (usually either latitude-longitude or UTM coordinate systems). The closer the grid points in the file, more is the detailed information contained in the file.

Among the enumerable applications, the generic applications of DEM include - extracting terrain parameters, modeling water flow or mass movement (say, avalanches and landslides), creation of relief maps, rendering of 3D visualizations including flight planning, creation of physical models, rectification of aerial photography or satellite imagery, terrain analyses in geomorphology and physical geography, Geographic Information Systems (GIS), engineering and infrastructure design, Global Positioning Systems (GPS), line-of-sight analysis, precision farming and forestry, Intelligent Transportation Systems (ITS), Advanced Driver Assistance Systems (ADAS). DEM's are also utilized in support of the pre-planning and lay-out of corridor surveys, seismic line locations, construction activities, and environmental purposes as shown in the following literatures [2], [14], [11], [12], [42], [46].

DEM registration is technique to represent DEM in congregation with either another DEM or map or an image. This paper is an attempt to do DEM-to-DEM registration at its initial phase and then follow it up with generalization, i.e., DEM-to-topographic maps and DEM-to-image registration including the resolution variations. In this literature, section II describes briefly the current literatures for DEM registration and a few of their shortcomings. Proposed method for doing DEM-to-DEM registration is discussed in Section III followed by results and error analysis in Section IV. The paper is wound-up by conclusion and future work projection in Section V.

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II. Preliminaries

A. Sources of DEMs

There are three main sources from which DEMs are usually contrived: (1) Interferometric Synthetic Aperture Radar (InSAR), (2) Stereographic images using the correlation among digital images [8], (3) interpolating of digital contour or topographic maps [12].

For creation of DEMs it is important to have the elevation values that act as data sources of the earth at the point that is represented in the DEM. A few of the methods that provide these are: (a) Real Time Kinematic GPS, (b) stereo photogrammetry, (c) Theodolite or total station, (d) Doppler radar, (e) Focus variation, and (f) Inertial surveys. Satellites that provide good input for producing DEMs include Geosats, ERS-1/2 (ESA), Landsat TM (Landsat 4 and 5) and ETM+ (Landsat 7), ALOS, PRISM, PALSAR and other SARs, AVNIR-2 among others [8],[9],[10],[12],[16],[17] .

B. Representations of DEMs

DEMs may be stored and represented as: (i) Raster or grid (RSG – Regular Square Grids) also called Raster DEM and (ii) Triangular Irregular Network – (TIN) model or Vector DEM [7], [14], [22]. The characteristics of DEM so generated depend on certain parameters, some of which are enumerated as follows: (i) terrain roughness; (ii) sampling density (elevation data collection method), (iii) grid resolution or pixel size, (iv) interpolation algorithm, (v) vertical resolution, (vi) terrain analysis algorithm [12].

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C. Review of Literatures

DEM registration is important as it allows for seamless integration of DEMs of the same locality which may have been represented in different orientation, or may have been processed using different resolutions. Most DEM registration methods include DEM-to-topographical map registration or DEM-to-Remote Sensed Images registration. There are only a handful of methods for DEM-to-DEM registration. DEM-to-DEM registration is elusive because of the difficulties of finding feature points or control points required for matching and evaluation and error analysis of the techniques so used.

Sefercik [1] used DEMSHIFT software for superimposing 2 DEMs. AML (ARC Macro Language) – software created by ESRI for generating end-user applications in ARC/INFO Workstation was described by Ali, Adnan, Tahir, Rahman, Yahya, and Samad [23]. Li Yao, and He Chen [30] used OPENGL for reading the USGS Standard format DEM data and gave two ways of displaying the digital terrain's surface that included Triangle mesh and Construction of surfaces using NURBS curve.

Bambang Trisakti and Ita Carolita [2], proposed pyramid-layer-making for DEM generation and comparison between ASTER Stereo Data and SRTM DEMs which used a combination of XY coordinate points and height given by Z coordinate points as Ground Control Points (GCPs) for feature finding. They did accuracy evaluation by drawing vertical and horizontal transect lines along both the DEM images, followed by comparison of the height distribution of each transect lines. Zhengxiao Tony Li and James Bethel [3] performed two coarse DEM alignments - vertical alignment and horizontal alignment - as an initial step that gave input for the fine DEM registration. Thereafter, least squares matching method was used.

In the paper by LI Yong, WU Huayi [4], morphological gradient usage was proposed for DEM extraction from LIDAR data.

Maire & Datcu [5] constructed the visualization dataset by registering optical image and DEM using an object-based description of large optical EO (Earth Observation) images followed by fusion of the extraction information into the DEM by interactively selecting and classifying among a set of user-thematic. Hosford, Baghdadi, Bourgine, Daniels, and King, [6] described the fusion of airborne laser altimeter data and a stereo-radargrammetric DEM. In the literature by Pauline Audenino, Loi c Rognant, Jean-Marc Chassery, Jean-Guy Planes, [7] TIN – Triangular Irregular network Modelling is used to model the DEM from the terrain using Delaunay triangulation method. Top-down and bottom-up approaches for fusion were compared. DEM production and fusion of SAR images using area-based grey value matching was also done by Xinwu Li, Huadong Guo, Changlin Wang, Zhen Li and Jingjuan Liao [8]. Another GCP extraction algorithm based on geocoding of radar images requiring precise orbit information was mentioned by Sang-Hoon Hong, Jung, Won, and Hong-Gab Kim [18]. For the classification and mapping of land cover types and other environmental monitoring and planning purposes, Bucher, and Lehmann, [26] proposed a combination of the High Resolution Stereo Camera - Airborne (HRSC-A) and the HyMap hyperspectral scanner covers for generating a very high spatial and spectral resolution data and Digital Elevation Model (DEM) for the resulting Above Ground. Gauss Markov random fields (GMRF) models and a Bayesian approach were used to filter DEM. SAR TM and DEM fusion was shown by Takeuchi [31]. Lahoche, and Herlin [35] proposed a scheme for generating high resolution maps by the process of mapping individual temporal values on the classification image. Similar DEM-to-image and DEM-to-map registration method were also described in [27], [28], and [29].

In the paper by Howard Schultz, Edward M. Riseman, Frank R. Stolle, and Dong-Min Woo [33], a novel method was proposed – self-consistency measure for multiple DEM-to-DEM registration by detecting changes in the terrain elevation. They showed two-image stereo reconstruction and multi-view stereo reconstruction using feature matching and texture matching. They also divided the 3D reconstruction algorithms into image space methods and object-space matching. The basic principle is to identify outliers which gave unreliable elevations estimates, followed by computing a weighted average of all reliable points.

The Coarse to Fine (CTF) hierarchical operation using image pyramids (3-5 layers) was adopted into the DEM generation process by Junichi Takaku, Noriko Futamura, Tetsuji Iijima, Takeo Tadono, Masanobu Shimada, and Ryosuke Shibasaki [10]. Similar approaches for fusion of an orthophoto image and a DEM generated from PRISM was utilized by Futamura, Takaku, Suzuki, Iijima, Tadono, Matsuoka, Shimada, Igarashi, and Shibasaki [19]. Permanent Scatters methods were used for fusion of low resolution DEMs by Ferretti, Monti-Guarnieri, Prati, and Rocca [20]. PU (Phase Unwrapping) method was used by authors in [25] for Multi-interferogram and DEM fusion. In another paper by the same [32] proposed a method for removal of phase distortions and combining DEMs in wavelet domain by means of a weighted average.

DEM calibration for estimation of systematic height errors was performed by Wessel, Gruber, Gonzalez, Bachmann, and Wendleder [13] in which they used the least square adjustment approach along with calibration reference data incorporating tie-point concept with GCP. Error analysis and validation were also done by Jie Li, Haifeng Huang, and Diannong Liang [24] using Monte-Carlo simulation. RMS accuracies were checked in Belgued, Rognant, Denise, Goze, and Planes [15]. Steven Bowe [36] also performed error and accuracy measurements in his paper.

Most of these methods, apart from being time and complexity intensive, lack in error matrix evaluation. Also, none prove to be suitable for different resolution DEMs. This paper not only proposes a novel method for DEM registration by using their basic ASCII values but also an error analysis of the same is presented in the following sections.

III. Proposed method for DEM-to-DEM registration

Generally DEM Registration may be achieved by performing the following set of steps:

1. Procurement of DEMs – atleast one of high quality which may be considered as the reference DEM

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against which error measurement and analysis is also done.
2. Finding quality feature points to be matched.
3. Alignment of DEMs to be registered. This includes Ortho-rectification.
4. Fusion of DEMs based on their Control Point matching and resolution
5. Enhancement and output generation.

DEMs may be procured freely from some of the sources which provide DEMs like (i) GTOPO30 (30 arcsecond resolution, approx. 1 km), (ii) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument of the Terra satellite - 30 meter resolution, (iii) Shuttle Radar Topography Mission (SRTM) data – 3 arc-second resolution (around 90 meters), (iv) TerraSAR-X:a German Earth observation satellite [47], [48]. Though not all but some of these provide good and high resolution (upto 1 arc) DEMs which may be used as a set of reference DEM for registration and error evaluation purpose.

Steps followed are:

1. Convert the DEMs to ASCII format. This can be performed directly from the DEMs themselves by using a freeware viewer like 3DEM [16], as shown in Fig 1 that allows user to convert and save the DEM to ASCII format. This ASCII file is a text file containing height values. Free DEMs may be downloaded from a number of sources. The DEM used in this project was from [45].

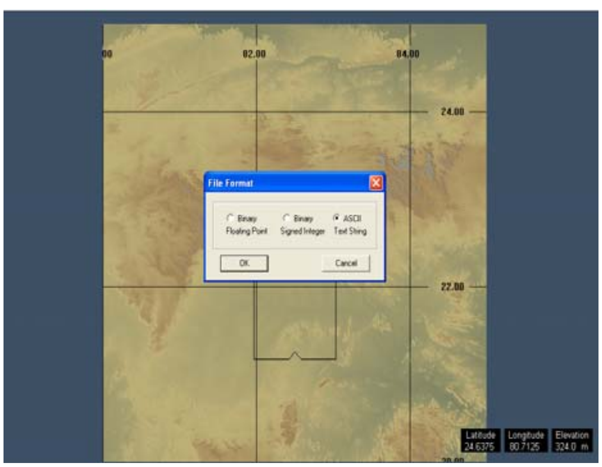

Fig. 1 Convert a DEM from Geotiff format to ASCII file
Courtesy: http://3dem.ucsd.edu/

2. These ASCII files are then compartmentalize these to manageable sizes as it would require a colossal sized RAM for processing. The breaking down process from parent ASCII file to the children ASCII files doesn't require much processing and is hence easier to handle.

3. Feature point finding. This step involves getting the initial set of points from the user. Currently this is a manual process, so all the points are entered by the user. These points may be directly marked from either the DEM viewer or from the viewer created to read and render the ASCII file. A few control points have been shown as marked in Fig. 2. These points are then stored in a file. The file stores 3 parameters for each point marked – the latitude, longitude, and the elevation data. These control points to be matched are then found in the candidate DEM. The experimentation presently done considers two methods of doing this. First, since, ASCII data is being used, usually the data matched is accurate, but, some times, due to the difference in resolution at which these DEMs have been processed, the data matched gives a few false positives. The second method consists of edge matching along congruent quadrangle of the control point.

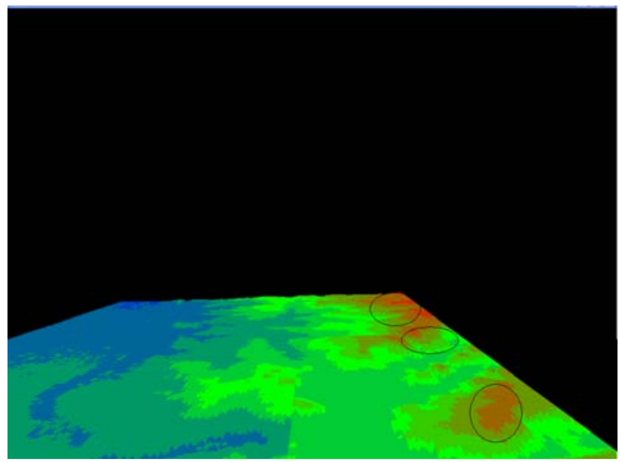

Fig. 2 Control Points marked in the reference DEM as small black dots.

4. From the ASCII file, with reference to the initial DEM, retrieve the latitude and longitude combination (the best match is considered) in the DEMs to be registered. Presently since the DEMs have either the latitude or longitude alignment, it is not too intricate to match.

5. Form a parent graph of the points considered as control points from the reference DEM. Once these points are found in one or multiple files, form graphs from these points too. These graphs must actually be a sub-graph to the original graph if control points are accurately found. Fig 2 shows the reference DEM in which the control points have been marked manually. Fig 3 shows the DEM of a candidate ASCII file in which control points have been found along with a false-positive matches. Some of the control points have been highlighted.

6. Find the orientation of the sub-graph with respect to the parent graph. Accordingly do the vertical and horizontal orientation of the DEMs. Form a third ASCII file combining the data from the parent DEM and the best matched candidate DEM. (Direct

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joining of tiles of data is possible by providing latitude and longitude data.)

7. Display the ASCII file, so generated, by using dynamic color coding as shown in Fig 4.

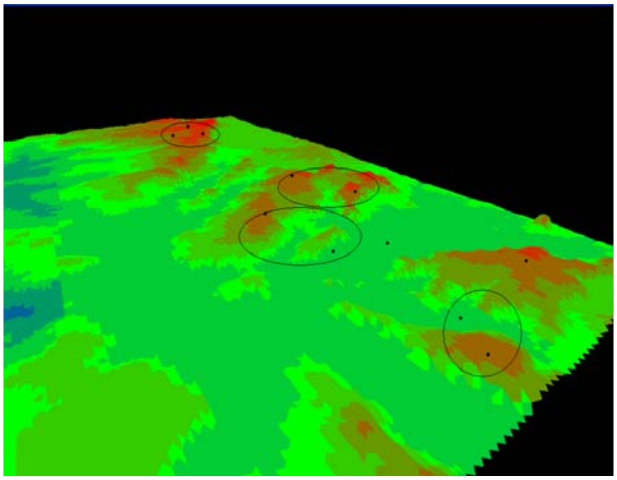

Fig. 3 Control points found in the candidate DEM. Few false-positives are also seen.

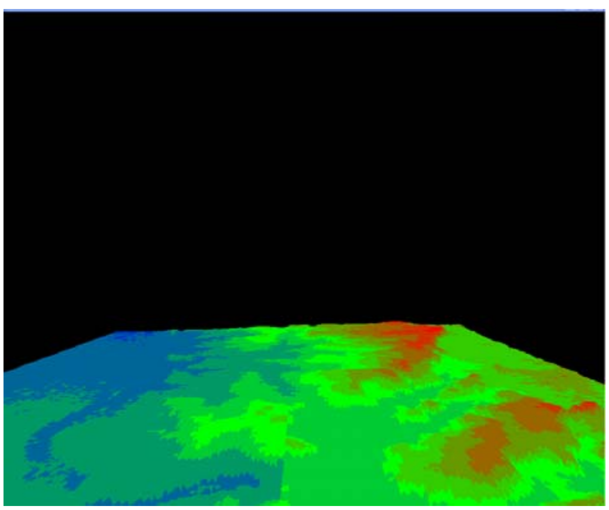

Fig. 4 Display of the registered DEM (registered from reference and candidate DEM).

Though sub-graph matching is said to be a computationally difficult, since, herein, only a limited number of matching points are considered, it gives a better solution as compared to other feature-point finding techniques. Another advantage of this technique is that it can work with DEMs having almost any resolution. A DEM that could be converted to its correct ASCII values could be used as an input for DEM-to-DEM registration using the above mentioned technique. Also, because the ASCII file of the candidate DEM file is, beforehand, partitioned into manageable and small-sized children ASCII files, the time complexity is greatly reduces for the DEM-to-DEM registration of reference and candidate DEMs.

IV. Results

For experimentation initially 40 control points were considered from a matrix of 300 x 300 points. These points were marked manually. The various criterias for evaluation of error considered were – mean value comparison, Root Mean Square Error (RMSE) finding, Total Squared Curvature error and t-statistic error analysis.

Though only 40 points have been considered initially, some of the common problems faced were – detection of too many false matching due to thresholding leaving a huge margin for error removal, and time & complexity heavy computation. Also, presently only the same-resolution DEMs were used for experimentation. The error factors would probably increase as the complexity of DEM grows. Table I, shown below, gives a compact view of the various results derived after error analysis by the methods of mean difference of the matched points with the actual marked control points, RMSE differences, and Total-squared curvature error and t-statistic error values. These comparisons are for the two methods of direct control point matching and edge matching technique using congruent quadrangles of the control points respectively as mentioned in the Table I.

Table I. Results of comparison of the various error analysis techniques used in this literature.

Matching technique	Error Analysis (difference in %, approximate values are provided and only for the test cases)			
	Mean difference	Root Mean Square Error (RMSE)	Total Squared Curvature	t-statistic error analysis
Direct Control Point matching	12.5	8.23	3.45	3.25
Edges matching along congruent quadrangle of the control point.	8.56	7.78	3.01	3.01

V. Conclusion

This paper describes the experimentations performed for registration of DEMs. For this experimentation DEMS of same resolution have been used. The methods used for registration, has been described. Results in terms of error evaluation have been shown. For display of ASCII data, dynamic color coding is used which lacks terrain look but still manages to give a good idea of the height difference in the area. The feature-point finding and matching technique may be extended by using morphological operations.

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