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Generation and Evaluation of Accuracy of Digital Elevation Model Data Derived From Universal and Topographic Stereo-plotters Using Electronic Data Acquisition Systems

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Abstract— **In circumstances where upgraded stereo-plotters and a set of aerial photos are available, digital terrain model (DTM) data can be acquired to an accuracy level comparable with that obtained using much expensive analytical and digital instrumentation (i:e ± 0.2m - ± 0.5m). Such accuracy figure is commensurate with the requirements of a number of civil engineering, cartography and other application areas with much savings in cost. .**

Index terms **-- stereo-plotters, Digital Terrain Model (DTM), planimetric accuracy**.

I. INTRODUCTION

Up to the mid 1980's, photogrammetric projects and practices were dominated by and reliant on a multitude of special-purpose instrumentation. These included stereo-plotters, mono- and stereo-comparators, point-marking devices, automatic dodging printers, ortho-photo projectors as well as various kinds of hard copy plotting devices (Chen and Guevara, 1987).

These instruments were manufactured by companies with decades of experience in modeling the geometry of frame (or metric) photographs. Most of these were indeed marvels of optical and mechanical craftsmanship. Thus, a well-maintained stereo-plotter could put in 30 or 35 years of excellent service with minimum upgrades. However, these instruments are now gradually being supplanted by general-purpose (or even PC) digital computers, special-purpose photogrammetric software and high-resolution raster display screens all operating on digital imagery. The photogrammetric film scanner and computer-compatible stereo viewing systems are emerging as the only special-purpose hardware components necessary for the photogrammetric workstation. Even the scanner is now gradually giving way to direct digital cameras and sensors.

II. TOPOGRAPHIC AND UNIVERSAL STEREO-PLOTTERS

Stereo-plotting instruments are generally classified into:

(1) direct optical projection instruments (e.g. Multiplex or Kelsh);
(2) instruments with mechanical or optical-mechanical projection (e.g. Wild A7, A8, B8, Kern PG-2 etc);
(3) analytical plotters (e.g. I2 S Alpha 2000); and
(4) softcopy stereo-plotters (workstations).

The first category is now seldom used. However, many national mapping agencies worldwide had invested billions of dollars in purchasing and operating thousands of the second category for a period extending for over 70 years. This category of mechanical projection stereo-plotters is further classified into topographic plotters which were specifically manufactured for topographic mapping at large and medium scales utilizing aerial photographs taken with camera lenses having focal length of around 150mm; and universal stereo-plotters designed for topographic mapping, aerial triangulation and in some designs for processing of terrestrial photographs. These latter instruments have the capability of base in / base out setting, a main characteristic of the earlier methods of aerial triangulation (photogrammetric control extension).

As time dragged on, these instruments underwent a series of development and upgrade operations to improve their operability and efficiency through either electronic connection to TA digital plotting tables with digital servo-drives for continuous automatic plotting or by incorporating electronic data acquisition systems through digital encoders for recording model coordinates to be used in independent model triangulation computations (Figs. 1 and 2).

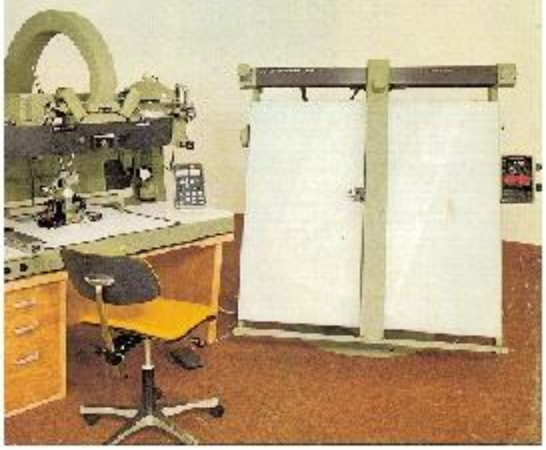

Fig.1: Aviotab TA Digital Plotting Table Connected to a B-8s Topographic Stereo-plotter.

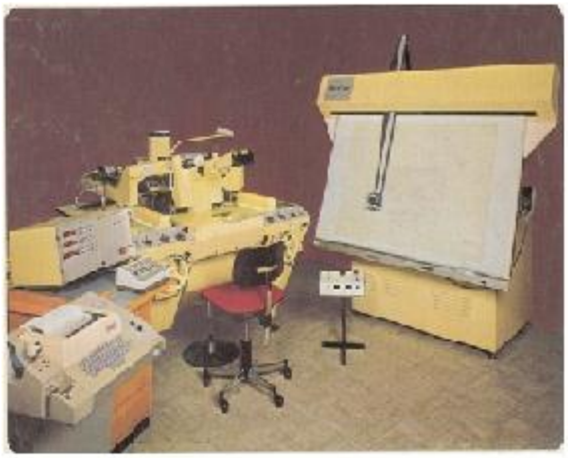

Fig.2: Data Acquisition System ER2 connected to a Kern PG-2 Topographic Stereoplotter.

Although these innovative combinations are now gradually being replaced by modern fully digital methods, the need may arise where topographic information is urgently required at low cost e.g. for international or national relief supply works, reconnaissance surveys for road and rail construction, canalization and across-province water supply projects, electrical power transmission surveys, placement of telecommunication towers etc. This is specially true when a sparse network of elevation points is needed. If aerial photographs from past projects are already available, then upgraded traditional stereoplotting machines may offer an economical alternative to present day surveying instrumentation e.g. total stations, GPS receivers and appropriate software, lidar surveys and high resolution satellite imagery e.g. Quickbird or IKONOS data.

The objective of this article is, therefore, to evaluate the possibility of using these upgraded stereoplotters for the generation of accurate digital elevation model (DEM) data making use of these ubiquitous instruments.

III. DIGITAL ELEVATION MODEL (DEM)

The earliest applications of photogrammetry were in topographic mapping . At present , most national mapping agencies in the world perform almost 100% of its map compilation photogrammetrically . Governmental departments of transportation use photogrammetry (or its clones e.g. high resolution satellite imagery) almost exclusively in preparing their topographic maps. Private engineering and surveying firms prepare many special-purpose topographic maps photogrammetrically . These vary in scale from large to small and are used extensively in planning and designing highways , railroads , rapid transit systems , bridges , pipelines, aqueducts, transmission lines , hydroelectric dams , flood control structures , river and harbor improvements , urban renewal projects, drainage systems ,landslide studies , road maintenance requirements and evaluations , etc. . A huge quantity of topographic maps are prepared for use in providing spatial data for geographic information systems (GIS).

Two newer photogrammetric products , orthophtos and digital elevation models(DEMs) are now often used in combination to replace traditional topographic maps . An orthophoto is an aerial photo that has been modified so that its scale is uniform throughout . Thus orthophotos are equivalent to planimetric maps , but unlike maps which show features by means of lines and symbols , orthophotos show the actual images of features . For this reason , they are preffered by many civil and surveying engineers in many everyday works. DEMs are vertebral to the preparation orthophotos (Baltsavias, 1996, Fritsch, 1996 , Carter, 1998).

A digital elevation model (DEM) is an analytical or digital representation of the surface of the terrain. It is a matrix of size n×3 where n is the number of terrain points representing the model and the figure 3 denotes the three coordinates of terrain points X,Y,Z. Digital elevation models are generated using one of the following data collection techniques:-

(i) digitizing a stereomodel created in a stereoplotter (Mikhail et al, 2001);
(ii) collecting survey data using traditional data collection instrumentation e.g. total stations, theodolites combined with leveling works, electronic tacheometry and global positioning systems (GPS) , see Helmering, 1978);
(iii) direct digitizing of topographic maps i:e those showing contour lines as well as prominent planimetric features (see Robinson,1994);
(iv) utilizing light resolution still-picture video images (Mass and Kersen, 1997);
(v) obtaining stereoradar images (Abdou, 2008);
(vi) collecting lidar system data (Fluch and Wolfing; 1998); and
(vii) Using high resolution stereoscopic satellite data e.g. from SPOT HRV instruments (Chen and Lee, 1993, Al-Rousan et al, 1997 , Giles and Franklin, 1996) .

As mentioned before, because of the rapid advance in computer technology, DEMs have found a multitude of applications in everyday life and are now widely accepted as one main source of topographic and land information. Following are some examples:-

- calculation of optimum design parameters in highway engineering, earthworks, drainage canals, rail road design etc. (Benjamin and Gaydos,1990);
- DEM constitute ready off-the-shelf data that can be used directly as input to a land or geographic information system (LIS/GIS) (Algarni,1996 , Fritsch,1996 , Carter, 1998, Merchant, 1999, Baltsavias, 1996);
- Orthophoto production (Hohle ,1996, ; Baltsavias, 1996);
- Fast and precise change detection studies. (Acharya and Chaturedi, 1996).
- Line-of-sight engineering studies and urban analyses (Leberl et al,1999).
- Automatic building extraction studies (Lammi, 1997, Lee, 1991);

IV. DATA ACQUISION SYSTEMS

In some occasions, the coordinates of only a relatively small number of points need to be measured; and in others, the coordinates of many points are required but not very urgently (see e.g. Benjamin and Gaydos, 1990). For such circumstances, manufacturers had introduced electronic data acquisition systems to be connected to topographic and universal stereoplotters.

Generally, these systems consist of three incremental digitizers, which are mounted on the stereoplotter, as well as three commercially available digital displays. The digitizers convert the three dimensional displacements into basic electronic signals the period of which corresponds to the distance interval of the model. The digitizer signals are fed to the corresponding counter which adds them algebraically. The results of the measurements for each coordinate are continually displayed usually at a 5-digit display with nixie tables. Initial coordinates are set by decade switches and upon pressing a pre-set key are fed to the counters and the display. A built-in +/- selector allows a change in direction of counting for the same direction of movement. Different fitting arrangements are used for the different stereoplotters. Popular data acquisition systems are the EK12, EK2, EK22 and EKU from Wild and can be utilized with Wild Aviograph and Autograph srereoplotters and ER2 from Kern which is used with the Kern PG2 srereoplotter.

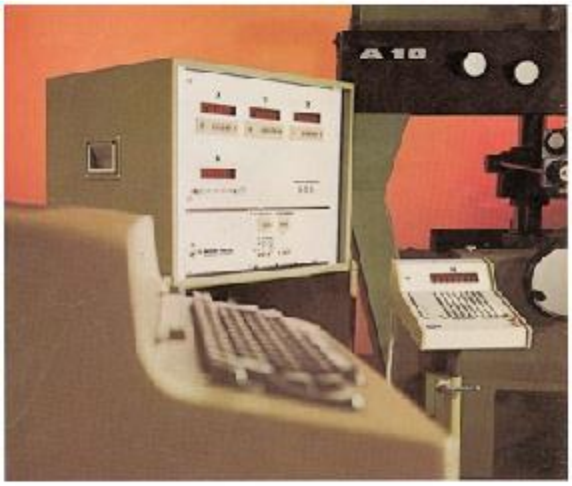

Fig.3: Wild EK22 Connected to a Wild A-10 Universal Stereoplotter.

V. TEST MATERIAL AND PROCEDURE

The material used in the present test consists of two photographic stereopairs taken over a moderately hilly area (root- mean- square relief variation of ± 50m). The photographs of the first stereomodel have a scale of $^{1}/_{1}0000$ while those of the second were at a $^{1}/_{2}0000$ scale. The first model contains 27 photo control points whose terrain coordinates are available to an accuracy of ± 0.02m in planimetry and height. The second stereomodel has 22 photo control points on it. The accuracy of these points is also known to be ± 0.02m in planimetry and height. The positions of all these points were carefully marked using a Wild PUG-4 point marking device. The photos of the first model were taken with a wide angle aerial camera having a focal length of 152.07mm from a flying altitude of 1521m. Those of the second model were obtained from an altitude of 3025m using a camera with a focal length of 151.25mm. The photographs forming the two stereomodels were of excellent quality and the corresponding prints were in high quality glossy paper which assisted greatly in photo point identification.

Essentially, the method of approach is to connect the appropriate data acquisition system to the stereoplotter. Inner, relative and absolute orientations were then carried out with utmost care and vigilance. After completing this step, model coordinates of all marked points were digitized using the data acquisition system.

In order to transform model coordinates to ground coordinates, an analytical absolute orientation programme was written and implemented. The input to the programme consists of the terrain coordinates of only four well-distributed points on each stereomodel and the model coordinates of all other digitized points.

The two models were mounted, oriented and digitized in the following stereoplotters.

- A Wild B8-S topographic plotter and an EK12 connected to it;
- A Wild A-8 universal plotter and an EK12;
- A Wild A-10 universal plotter and an EK22; and

- A Kern PG-2 with an ER2 attached to it.

For the sake of completeness, the same stereomodels were further processed in a Wild AC-1 analytical plotter using the same four control points. This allowed good comparison of the sets of results obtained. The final results of the experiment are shown in Tables (1), (2), (3), (4) and (5).

TABLE I
ACCURACY OF THE CHECK POINTS AS OBTAINED FROM WILD B8-S AND A WILD EK12 DATA ACQUISITION SYSTEM CONNECTED TO IT

Model Number	Photo Scale	σ_E (m)	σ_N (m)	σ_P (m)	σ_H (m)
I	$^1/_{10000}$	0.09	0.10	0.16	0.31
II	$^1/_{20000}$	0.10	0.12	0.17	0.44

TABLE II
RESULTS OBTAINED WITH THE WILD A-8 AND AN EK12 DIGITIZING UNIT.

Model Number	Photo Scale	σ_E (m)	σ_N (m)	σ_P (m)	σ_H (m)
I	$^1/_{10000}$	0.09	0.9	0.12	0.32
II	$^1/_{20000}$	0.11	0.10	0.11	0.38

TABLE III
ROOT-MEAN SQUARE ERRORS AS OBTAINED WITH THE WILD A-10 AND AN EK22 CONNECTED TO IT.

Model Number	Photo Scale	σ_E (m)	σ_N (m)	σ_P (m)	σ_H (m)
I	$^1/_{10000}$	0.08	0.08	0.11	0.26
II	$^1/_{20000}$	0.09	0.08	0.12	0.36

TABLE IV
RESULTS OBTAINED WITH THE KERN PG-2 WITH A KERN ER2 DIGITIZING UNIT ATTACHED TO IT

Model Number	Photo Scale	σ_E (m)	σ_N (m)	σ_P (m)	σ_H (m)
I	$^1/_{10000}$	0.12	0.11	0.16	0.32
II	$^1/_{20000}$	0.11	0.11	0.16	0.53

TABLE V
RESULTS OBTAINED WITH THE ANALYTICAL PLOTTER WILD AC-1.

Model Number	Photo Scale	σ_E (m)	σ_N (m)	σ_P (m)	σ_H (m)
I	$^1/_{10000}$	0.08	0.9	0.12	0.24
II	$^1/_{20000}$	0.07	0.08	0.11	0.27

VI. ANALYSIS OF THE RESULTS

Although the contents of Tables 1 to 5 are self-explanatory, one needs to elaborate on them. For model I (photo scale $^1/_{10000}$), the planimetric accuracy of DEM data generated in analogue stereoplotters connected to electronic data acquisition systems ranged from σ_P = ± 0.11m with the Wild A-10 universal plotter to σ_P =± 0.16m obtained with the two topographic plotters Wild B8-S and Kern PG-2 using the two data digitizers Kern EK12 and EK2 respectively. It is noted that when the EK12 and the EK22 were connected to the universal plotters (the A-8 and the A-10), the planimetric accuracy of the DEM improved by around 20%. In fact a quick glance at Table (5) shows that the planimetric accuracy of DEM data obtained with data acquisition systems attached to the universal stereoplotters A-8 and A-10 is of the same order of magnitude as those obtained with the analytical stereoplotter AC-1 i.e. around 0.10m to 0.15m (see e.g. Bolstad and Stowe,1994 , Ali, 2006, 2008).

For model II, the planimetric accuracy of the generated DEM data ranged from σ_P= ±0.11m with EK12 attached to the A-8 to σ_P = ±0.17m with the EK12 and the B8-S. Again, the data acquisition systems EK12 and EK22 performed markedly better when connected to the universal stereoplotters A-8 and A-10 thus giving DEM accuracy figures comparable to those obtained with the AC-1. Table (6) represents the DEM planimetric accuracy expressed at photo scale as some engineers prefer results be presented in this manner (Torlegard, 1986).

Such range of DEM accuracy is commensurate with a number of civil and surveying engineering works e.g. urban planning (Leberl et al , 1997 , Sinning et al,1996), Lammi,1997), cadastral surveys (e.g. Algarni (1996)), road surveys (e.g. Benjamin and Gados ,1990) , environmental analyses (Douglas ,1995), assessment of transportation safety (Padgett,1992), pavement management (Voss,1991) etc .

The height accuracy, the most important characteristic of DEM data, ranged from σ_H = ±0.26m with the A-10/EK22 combination to σ_H = ±0.32m with the A-8/EK12 and the PG2/ER2 combination systems for model I. The corresponding figures obtained with model II were σ_H = ±0.36m with the A-10/EK22 system to σ_H = ±0.53m with Kern PG-2/ER2 system. In all cases, therefore, the accuracy figures obtained are commensurate with the accuracy needed

TABLE VI
PLANIMETRIC ACCURACY AT PHOTO SCALE

Instrument + Data Acquisition System	Accuracy at photo Scale	
	Model I	Model II
B8-S + EK12	16μm	8.0μm
A-8 + EK12	12μm	5.5μm
A-10 + EK22	11μm	6μm
PG-2 + ER2	16μm	8μm
AC-1	11μm	5.5μm

for contour line plotting at an interval of 1m which meets the requirements and standards of many civil engineering, cadastre, town planning and other similar projects (see e.g. Lembo and Hopkins , 1998, Leberl et al ,1997, Benjamin and Gados, 1990, Algarni,1996 etc.)

Comparison with the results obtained with AC-1 shows that with these upgraded versions, DEM accuracy figures comparable with those obtainable using analytical stereoplotters could easily be obtained with much savings in time, effort and resources.

DEM height accuracy is customarily expressed as per mil of the flying height. A quick glance at Tables 1 to 5 shows values of around 0.2‰ for both models, again meeting the requirements of many civil engineering and other surveys.

VII. CONCLUSION

In cases where an upgraded analogue stereoplotter and a set of aerial photographs of the project area are available, DEM data could be generated with an accuracy comparable to that obtained with an analytical stereoplotter with no extra cost incurred i.e. around ±0.11m to ±0.15m in planimetry and ±0.32m in height . Such accuracy level is commensurate with a multitude of civil engineering, agriculture, geology and town planning projects where only a sparse network of elevation data is not very urgently needed.

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