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The Use of an Automatically Generated DTM for Mapping at Different Scales

Dr. Marco M. Leupin
M. Cherkaoui, M.Sc.
Dept. of Photogrammetry and Remote Sensing
Laval University, Quebec City, Canada

Abstract:

Canada's vegetationless North is being mapped with the aid of the Gestalt Photomapper. The automatically created DTM based on the 1:40'000 image scale results in a dense grid with a point roughly every 8 meters. In order to investigate further uses of this DTM in zones with vegetation and extend its applicability to different mapping scales, a test model close to Montreal was selected. The DTM was compared to an existing 1:5'000 map of the same region, giving a good idea of its accuracy with different topography and vegetation. Based on statistical tests, conclusions were drawn as to the possibility of using the relatively dense DTM for larger scales, especially for cadastral related maps in which altimetry is usually without interest.

THE USE OF AN AUTOMATICALLY GENERATED DTM FOR MAPPING AT DIFFERENT SCALES

1. Introduction

Digital terrain models (DTM) or - more specifically - digital elevation models (DEM) are used more and more in map production and other applications. At the same time, land-information systems and data banks are propagated. However, such systems are always established in view of a particular application, be it topographical, cadastral, utilitary or other. Moreover, the data are collected in accordance with a certain accuracy related to the scale of the final graphical product.

This is a significant constraint and it is contrary to the basic scope of land-information systems. Unfortunately, there is not very much one can do about it, since nobody collecting data for a topographical 1:50'000 map will do it with the same accuracy and density in order to satisfy a 1:1'000 cadastral map. More likely, the reverse situation can be treated with modern computer technology, involving rather extensive filtering procedures.

On the other hand, many cartographic applications do not need the accuracy of topographical maps (e.g. thematic and ressource maps) or do not need altimetry (cadastral maps).

With the use of the Gestalt Photomapper, GPM-2, Canada'a, vegetationless, northern regions are presently mapped at 1:50'000. The Photomapper produces a dense DEM (a point every 7 m) grid based on 1:40'000 photographs. This grid has served as a reference in the present research, in which accuracy and potential applications are studied.

2. Test area

The Topographical Survey Branch of the Ministry of Energy, Mines and Ressources placed two 1:40'000 test models, close to Montreal's new Mirabel airport, at our disposal. The area was chosen because of its variety in topography and vegetation (flat and hilly terrain, clear areas and forests). In addition to that, the area is covered with a 1:5'000 map with 2 m contour lines derived from 1:15'000 photography. This material was to be used as accuracy standard for the various tests. A specific and characteristic zone was picked out for detailed studies. This zone is covered by 1 model at 1:40'000 and 1 model at 1:15'000.

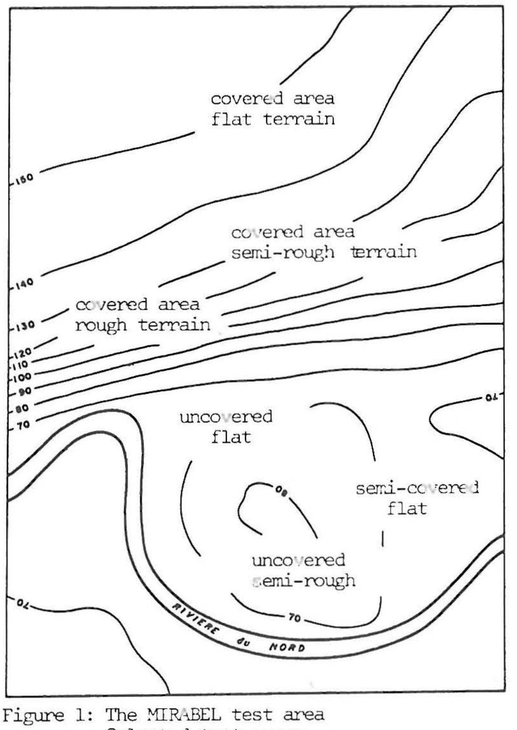

Figure 1: The MIRABEL test area
Selected test zones

3. Data description

The original D.E.M. was produced on the gestalt Photomapper GPM-2 at the Topographical Branch. The GPM-2 has widely been described recently and there is no need to reiterate its features (see e.g. /2/). The DEM, gained through automated correlation based on the 1:40'000 photography, has a grid density of roughly every 7.0 m a point. The mask chosen on the GPM-2 was # 2 (mean value) which, under practical conditions, would have been the selected value to represent the topographical situation of the area. The total of 620'000 points seems sufficient to conduct this kind of investigation.

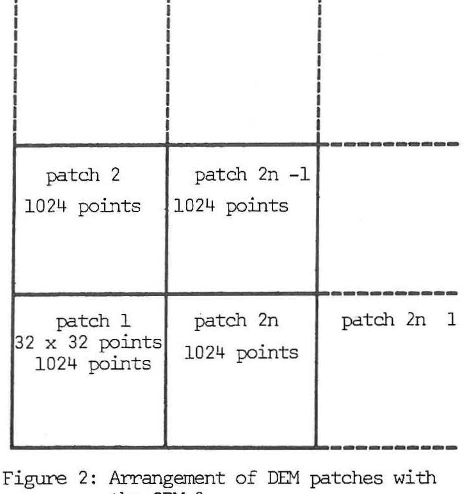

Figure 2: Arrangement of DEM patches with the GPM-2

For the reader not familiar with the DEM structure produced by the GPM-2, it may be reminded that the DEM is arranged in groups, production units called "patches". One patch (in our case with # 2 mark) measures 5.82 mm x 5.82 mm and contains 32 times 32 elevations, giving 1024 points per patch (see Fig. 2).

In order to be able to compare these values to the existing map, they have been transformed into the UTM system and marked on a 1:5'000 Cronaflex sheet. This has been done with the help of a high-precision *Haag-Streit* coordinatograph which claims to have a point accuracy of ± 0.03 mm. Using all of the 620'000 points would have been a formidable task and consequently 400 points were picked out by skipping the remaining points, but still forming a regular grid. The mapping scale was 1:5'000.

After a careful relative and absolute orientation of the 1:15'000 model on a A7, the spotheights of all 400 points were plotted. The values of the spot heights obtained through the GPM-2 with 1:40'000 photography and the spot heights obtained on the A7 with 1:15'000 photography form the basic data set to be investigated.

4. Accuracy of the basic data

The following tables give an idea of the model accuracy for 1:40'000 and 1:15'000 as obtained through a spatial transformation (absolute orientation).

Control-point	V_x (m)	V_y (m)	V_z (m)
509	0.20	- 1.84	0.28
511	2.25	0.24	0.92
416	- 1.51	0.90	- 0.54
414	- 0.75	0.68	0.19
510	0.65	0.38	- 2.37
415	- 1.54	- 0.96	1.01
	$\sigma_x = \pm 1.47$	$\sigma_y = \pm 1.07$	$\sigma_z = \pm 1.25$

Table 1: Absolute orientation, model 1:40'000
(GPM-2 results)

Control-point	V_x (m)	V_y (m)	V_z (m)
85096	- 0.05	0.18	- 0.80
85106	0.21	0.30	- 0.50
75146	0.05	0.17	0.16
75156	0.09	0.03	0.10
85116	- 0.28	- 0.43	- 0.70
75166	0.07	0.00	0.15
75176	0.13	- 0.05	0.13
83097	0.03	0.14	0.15
83107	0.00	0.24	- 0.13

$\sigma_x = \pm 0.14$ m $\quad \sigma_y = \pm 0.23$ m $\quad \sigma_z = \pm 0.43$ m

Table 2: Absolute orientation, model 1:15'000 (A7 results)

All the selected 400 grid points which have been measured on the 1:15'000 model have been transformed numerically in the UTM system. The measured Z coordinate minus the GPM-2 Z coordinate for the same point represent the listed ΔZ.

A first glance at the table 3 shows immediatly that these must be a systemmatic effect in the ΔZ, due to a large overrepresentation of positive values. This was to be expected,

ΔZ m	Frequency
- 10	1
- 8	1
- 6	1
- 4	6
- 2	46
0	91
2	64
4	45
6	31
8	30
10	32
12	23
14	18
16	14

Table 3: Frequency distribution of the ΔZ.

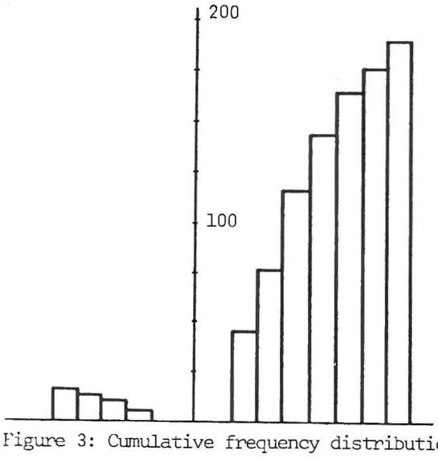

Figure 3: Cumulative frequency distribution

as all zones covered with forest must more or less show a ΔZ in the magnitude of the height of the trees.

Moreover, the three largest negative values seem to indicate some sort of blunder. A closer investigation showed that all three points were on a topographical break line (river) and that a small difference in the planimetric position could easily lead to such differences.

5. Elimination of the "tree effect"

Comparing the two DEMS in forest areas showed a regular ΔZ difference in the order of a mean tree height. It seems that in such areas the GPM-2 treats the tree-surface as correlation ground and (assuming a relatively dense and uniform tree population as often encountered in Canada) does it with consistency.

In order to evaluate the quality of the DEM in forest areas, all points of the test grid falling in such areas were picked out and underwent separate treatment. Moreover, different profiles were selected to help determine the Z shift due to the trees. Figure 4 shows the procedure.

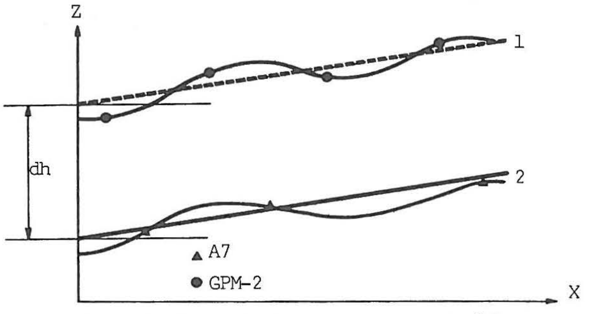

Figure 4: Determination of the tree height
$Z_i = a_o + a_1 X_i$ (line 1)
$Z_i' = a_o' + a_1 X_i'$ (line 2)

In all profiles, a line representing the terrain slope was found through least squares.

$$Z_i = a_0 + a_1 X_i + V_i \text{ for A7 profiles.}$$

$$Z_i' = a_0' + a_1 V_i + V_i \text{ for GPM-2 profiles.}$$

a_1, the slope, being the same in the two profiles.

The evaluation of different profiles is different zones yielded more or less identical results. With the now known coefficients, the ground elevations of the GPM-2 points can be found as

$$Z_i'' = Z_i' - a_0' + a_0 .$$

Figures 5, 6 and 7 show the result of this correction procedure. While in Fig. 5 we have the absolute frequencies of all the 403 points before the correction (the values listed in table 3), figure 6 shows the corrected result, with the cumulative frequencies in Figure 7.

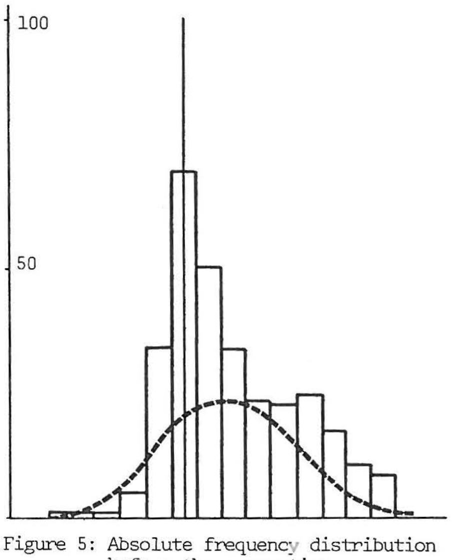

Figure 5: Absolute frequency distribution before the correction

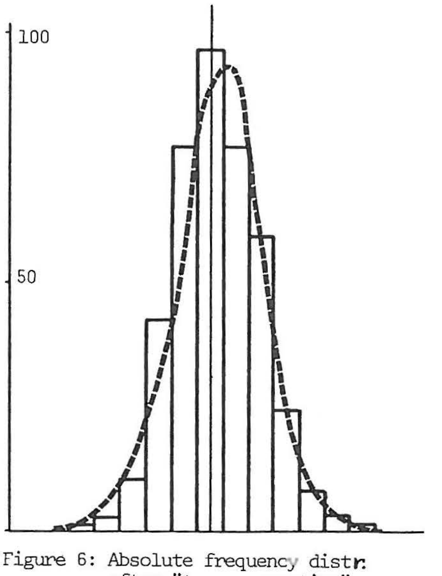

Figure 6: Absolute frequency distr. after "tree-correction"

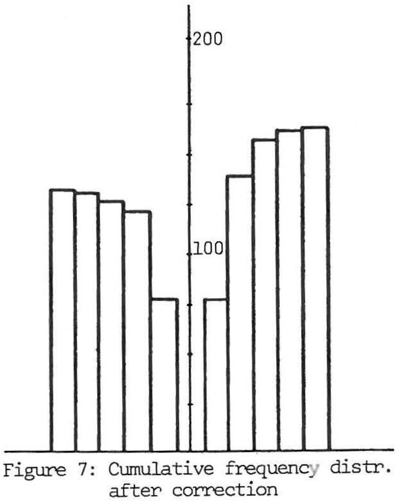

Figure 7: Cumulative frequency distr. after correction

6. Representative areas

In order to get an idea of the accuracy under different conditions, the test area was subdivided into 6 characteristic zones (see Figure 1). All these zones are represented by typical profiles. The results, with and without corrections, are given in Figures 8 to 13.

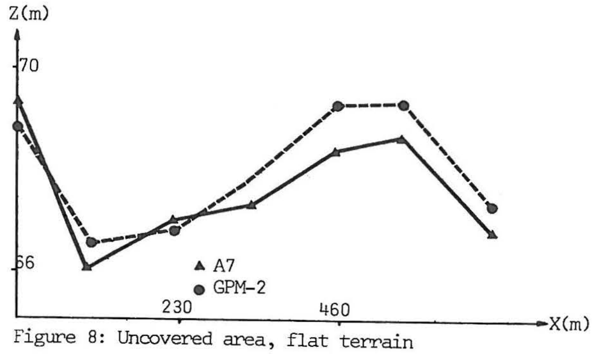

Figure 8: Uncovered area, flat terrain

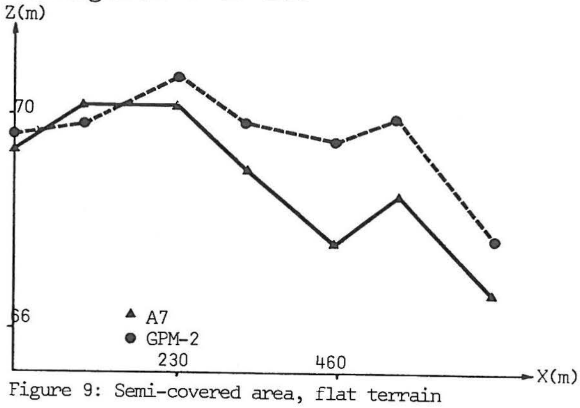

Figure 9: Semi-covered area, flat terrain

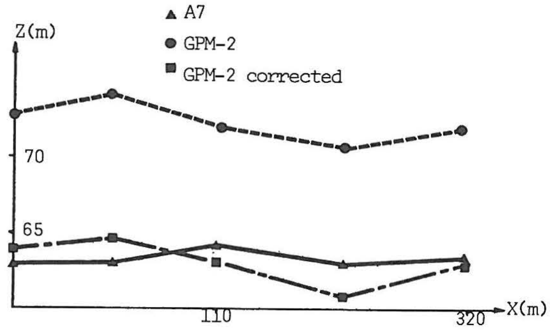

Figure 10: Covered area, flat terrain

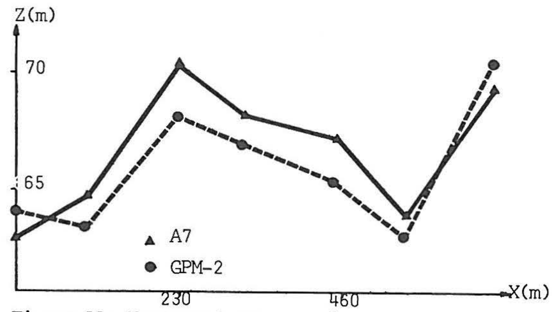

Figure 11: Uncovered area, semi-rough terrain

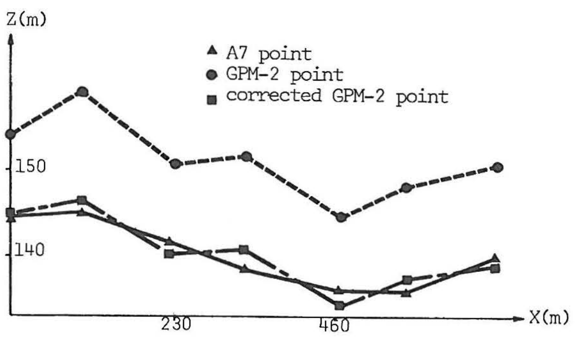

Figure 12: Covered area, semi-rough terrain

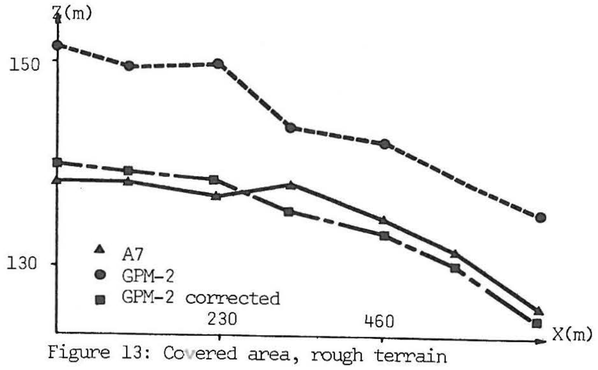

Figure 13: Covered area, rough terrain

After applying the "tree correction", all the ΔZ were submitted to a goodness of fit test, which should help to detect remaining systematic effects. The result was negative, showing no sign of systematic ΔZ.

7. Application to different scales

Far from being exhaustive, the study proves nevertheless that the DEM, produced on the GPM-2 at a 1:40'000 photo scale for the sole use of the 1:50'000 topographical map of Canada can be of wider use. The results obtained in the Mirabel test area, which represents a typical southern canadian topography and vegetation, are extremly encouraging.

An automatic procedure has to be found which detects forest areas on the image. In this areas the "tree correction" can be applied based on statistical data on mean tree heights. The resulting DEM can be used to produce maps at larger scales than 1:50'000.

To investigate this possibility, contour-lines were produced based on the corrected GPM-2 DEM and chosing the extreme mapping scale of 1:5'000. These contours were compared to the existing 1:5'000 map, which was produced observing the Quebec provincial tolerances for maps:

1:5'000	σ planimetric = ± 1 m	for control points on the
	σ altimetric = ± 0.45 m	map

and 50% tolerance of the contour interval (in our case ± 1 m) for contour lines, 25% (± 0.50 m) for spotted points.

In most parts of the test area, the coincidence of the contour lines is sufficient to satisfy the above mentioned tolerances. This is a very good result keeping in mind the 1:8 photo-map ratio. It is due partially to the extreme density of the DEM, which seems to drastically improve the overall accuracy.

8. Conclusions

Despite the drawbacks of automatically correlated DEM'S in areas with vegetation and artificial features, the comparison with existing maps are highly satisfactory. This is achieved by correcting the DEM for the "vegetation effect" (in practical terms the tree height) by subtracting a constant Z value. The fact that the GPM-2 produces an extremly dense DEM is an other factor that improved substantially the overall accuracy.

The DEM based on 1:40'000 photography is accurate enough to satisfy 1:20'000 map tolerances for topographical use. For other applications with less severe requirements in altimetric accuracy, larger scales can be produced.

The potential of a dense DEM, which in the not too distant future will cover the entire Canadian territory, looks extremly powerful and there is nothing limiting future applications in a wide range of cartographic domains.

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