PROGRESSIVE SAMPLING BY DIGITAL IMAGE MATCHING

A.G. Nwosu
Research Fellow, Department of Photogrammetry and Surveying
University College London, United Kingdom.
Tel ++44-71-3877050 est 2747 Fax. ++44-71-3800453
email gregory@uk.ac.ucl.ps

and

K. Tempfli
Associate Professor, Department of Geoinformatics
International Institute for Aerospace Survey and earth Sciences
Enschede, Nederland.
Tel ++31-53-874444 Fax ++31-53-874335
email Tempfli@.itc.me

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Abstract

Since state-of-the-art digital image matching currently has limited applications to large scale photographic images due to difficulties in coping with complex terrain and imaging conditions, an experimental package has been developed for digital image matching for an analytical plotter using the apparatus of progressive sampling. This allows for automated DTM data collection in un-problematic terrain and on-line intervention by the operator in case of problems. Compared to progressive sampling with manual measurements of height, or unsupervised digital image matching supplemented by manual measurements in the stereo model, the process aims at a better man-machine balance for an improved overall performance for DTM data collection for large scale applications. This report covers considerations taken for quality control, prudent segmentation of problematic areas, performance in problematic areas (like rough terrain with steep slopes, breaklines or buildings etc.), experiments on thresholding, and a case study.

Key words: Analytical, DTM, Image Matching.

1. INTRODUCTION

There remains a high demand for high quality Digital Terrain Models (DTM). While existing contour maps could be used, they may not always be available, may not have sufficient accuracy, or may be partly outdated. Photogrammetric techniques like contouring, profiling and regular grid measurements do not match the performance of Composite Sampling (CS) [1], which offers a good compromise of minimising measuring time, yet obtaining precise and comprehensive data. In CS, specific difficulties of large scales- like trees, buildings, bridges, etc.- can be handled by :

i) selective sampling or
ii) human intervention, during progressive sampling, by proximate (off-set) measurements.

A typical large scale model (say 1:4000 photography) to be measured by CS could be accomplished by:
i) 15 minutes of selective sampling and
ii) 5 hours of progressive sampling.

Photogrammetry is a major supplier of DTMs, and over the last 20 years has moved progressively from analogue equipment to analytical, and now, totally digital systems are increasingly being made available in some photogrammetric lines, offering an opportunity for faster processes at reduced cost, without necessarily conceding precision and reliability.

Progressive Sampling (PS) (Makarovic[2]) has been accepted as an efficient method of Digital Terrain Model (DTM) data collection, especially when combined with Selective Sampling(SS) (Makarovic[1]). In PS, the operator extracts the relief skeleton and also anomalous regions, attunes grid density to local terrain variability thus ensuring high performance with minimum effort. "Fine height setting" in open, bare terrain requires little interpretation. The operator only applies the fine setting of the floating mark on the ground and monitors whether all areas are sampled sufficiently. Although fine height setting can easily be done, the whole operation tends to become boring and thus liable to errors, making fine height setting in PS predetermined for automation, the basic idea being to leave for the operator those tasks of composite sampling that require intelligence, such as selective sampling, and for automation we leave the routine and repetitive tasks.

This can be achieved with CCD cameras installed in the KERN DSR11 and image correlation software which works reasonably well in 'easy terrain' (Petril[3]). It is based on the Vertical Line Locus (VLL) concept (see ([4][5] for more details) and this project was implemented on it. Experiments with the DSR correlators show that the system is easy to use, with only relative and absolute orientation as preprocessing. However, if applied, it takes about 3 times as much time per point as an operator on semi-automatic PS (4secs. versus 1.5secs. (M. Li[6]) and is 3 times less accurate (0.03% versus 0.01% of **H** (Cogan & Hunter [4]). The matching algorithm on the KERN DSR11 does not take terrain slope into account and is not recommended to be used for slopes greater than 30 degrees (Cogan & Hunter[4]).

Research on automated data collection for DTMs has been tremendous and followed two approaches, on-line correlation techniques and off-line digital image matching. Off-line systems are very desirable because they need not be time-efficient, therefore being convenient, plus the advantage of needing minimum special hardware, not to mention the phenomenal reduction in recent years in the cost of microprocessors and digital storage systems giving impetus the continuing improvements in performance. The inherent advantages of digital off-line systems, as stated by Sarjakoski (cited by Sasse & Altrogge[7]) are:

1) Stable Geometry of digital images.
2) No need for high precision mechanical components.
3) The possibility of incorporating the advantages of digital image processing and gain in speed.

They, however, have the disadvantage of needing costly storage space (Konecny & Pape[8]). Most state-of-the-art systems fall into this category though they are still experimental eg. multi-stage matching (Makarovic & Perreira[9]). On-line digital correlation is applied normally in the environment of an analytical plotter equipped with **CCD** cameras which scan and digitise small conjugate image patches for matching. On-line image correlation offers the possibility of direct operator intervention and support, especially appealing when large scale images are being processed. On-line systems have the disadvantage of more labour input, but have the advantage of refined performance due to the incorporation of decision strategies in real time, plus the need for small storage space [8].

Straight forward Digital Image Matching (DIM) has limited application yet to large scale photographic images due to the difficulty of DIM to cope with complex terrain and imaging conditions. Shadows occlude essential information in images; some images have poor signal variation of local image areas (texture); buildings and trees obscure the ground surface; steep terrain slopes cause geometric displacements in images. Other factors that could lead to failures are non-optimal image density, contrast etc.. These disturbances posing less problems to a human operator than to a set of algorithms, the human being superior still in selecting adequate points for terrain relief sampling. It, therefore, seemed interesting to experiment with a supervised approach based on available components. Aiming at an operational system on short term, the project was to find and implement a viable and efficient strategy to merge two sampling packages, **COPS** (Tempfli [10]) and **CORREL/DEMCOR** (Cogan, Hunter[4], Kern[5]).

The performance of digital correlation for DTM using the VLL concept is likely to improve if:

1) It is applied to areas well suited for correlation. SS could be used to delineate unsuitable areas in order to exclude them from digital image matching.
2) Good approximate values of height are available (Li Peng[11]). PS has a coarse to fine approach which eases the generation of good approximate values.

The major problem in combining CS with digital image matching is to find and implement a good strategy for man-machine interaction concerning relief modelling and quality control. The following questions arise:

1) what should the operator do in SS, prior to PS?
2) what should be done by PS, and when should the operator's interference be mandatory?
3) what should be done after PS?

Attempting to answer these questions requires to build an experimental system from the two working but autonomous components. The easiest and yet sufficient way is modifying the two packages independently and linking them through a data interface.

2. STRATEGIC ISSUES

Good threshold setting for PS is important for achieving a comprehensive terrain sample at minimum cost. A threshold too big leads to loosing detail of terrain relief, a threshold too small causes unnecessary measurements being enforced by noise (rather than relevant measurements which are governed by relief variability). The other important aspect is that blunders in height determination (mismatches, for example, top of buildings instead of ground surface) also have the effect of unnecessary measurements (dense sampling around the erroneous point) which should be avoided. Therefore, good threshold setting as well as good error detection procedures are imperative.

2.1 Thresholding (for terrain analysis)

In PS, data analysis by 2nd difference ([1 -2 1]) calculations which are compared with the pre-selected threshold is the basis for selection of new points for sampling. The standard deviation ($\sigma\nabla$) of a 2nd difference, based on the propagation of variances can be calculated as:

assuming no correlation then

$$\sigma o = \sigma$$
$$\nabla = h \quad -2h \quad +h$$
$$\sigma\nabla \approx 2.5 * \sigma o$$

where σo is the precision of the height measurement. For manual measurements it is in the order of 0.01% to 0.07% of flying height (**H**), depending on image quality, equipment, and operator. For digital image matching on the DSR1, measuring errors at neighbouring points are less homogenous, M. Li [6] reported a range of 0.035% to 0.070% of **H**. To avoid densifying the sampling pattern because of random measuring errors, the threshold should not be smaller than 2.5*0.03% of H.

Manual measurements normally do not show erratic deviations in precision between neighbouring sampled points. The heights of neighbouring points determined by digital image matching package tend to be correlated if the sampling sequence allows windows of neighbouring points to overlap. Otherwise, the errors at neighbouring points are often erratic. Experiments should provide more insight how these differences in the nature of the measuring error affect thresholding in PS.

2.2 Quality Control

In generating a DTM by image matching, two main problems are encountered at the operating level:

2.21) Failed Match 'Lost': This is caused mainly by dissimilarities of the two images caused by obstacles like trees, sometimes buildings, irregular terrain, electric poles, or lack of signal due to poor texture and the presence of clouds, water bodies and shadows. The solution offered by the CORREL package is that the operator intervenes and measures the height manually. The system that was developed in this project also requests the operator to intervene in cases of a suspicious height value.

2.22) Erroneous match: It is not unusual for image matching to be highly successful when homologous points are:

1) on top of a building or similar man-made objects,
2) on a large expanse of forrest/trees,
3) when there are periodic image patterns, or
4) when you have a homogenous image due to lack of image contents.
5) It should also be considered that the operator may absentmindedly trigger the measuring panel during remeasurements caused by failures.

These are sources of erroneous matches resulting in determined height-values being in gross error. Three possibilities of making checks on their occurrence are:

a) After each point is measured. This gives the simplest solution but the information available for the verification is very limited -essentially the measured value plus project parameters.
b) After each densification run of the sampling pattern in a patch. This reduces intervention and since more information is available from neighbouring points. However, the driving mechanism of the analytical plotter will traverse longer distances as interventions are enforced.
c) After each patch. This improves on the advantages of 'b' but if analysis takes place after all runs of a patch, we may have used a lot of gross-error points for terrain analysis, resulting in the possible selection of unnecessary new points for sampling.

In developing error algorithms, '(a)'was chosen with '(c)' as a refinement. 2nd difference analysis is done on all measured points to check suspicious points that may have escaped the earlier checks, and to fill gaps. This, due to RAM restrictions, has to be implemented in another module and, of course, its utilisation will be optional.

Analyzing measurements to detect gross errors could be implemented with the following different approaches :

1) 2nd difference computations could be compared against a threshold with care taken to choose and justify the threshold.

2) Slopes (delta h) could be calculated between neighbouring points and compared against some threshold chosen from knowledge of the terrain relief. However, during early runs when the grid is coarse, distances are long between points making analysis of calculated gradients run-dependent to avoid necessary interventions being bypassed.

3) A polynomial of sufficient degree could be fitted to the sampled points after each run (or after each patch) and deviations of individual sampled points compared against a chosen threshold. This approach is problematic and would impose heavy additional computation burdens that will adversely affect time efficiency. There is also the problem of deciding what degree of polynomial to use, not to talk of the result of having to work on a cluster of erroneous points.

To improve applicability to large scales choice favoured a simple approach of comparing measured values with the predicted ones (ie. approximate height that is calculated apriori) against a chosen threshold.

3. SOFTWARE DESIGN

(PS-DEMZ) evolved from changes to the COPS and CORREL/DEMCOR packages (see Nwosu [12] for full details).

3.1 COPS

The modules of COPS for selective sampling SS and patch/run management, were not changed. The major changes to COPS had to do with disabling manual measurement by the operator, except for zero-run which is the initial measurement of a 9-point coarse grid per patch. For the time being, manual measurements of the initial coarse grid provides the best assurance to obtain a good basis for computing approximate values for the subsequent densification runs [Nwosu 12].

3.2 CORREL/DEMCOR

A new application package 'DEM' replaces DEMCOR. Its multi-tasked integration with 'CORREL is 'DEMZ', while the integration of 'DEMZ' with 'PS' shall be referred to as **'PS-DEMZ'** (the new package).

(PS-DEMZ) has the following vital modules :-

PS_PSCORP - called only once at the beginning for initiation.
PS_ANAP - called for analysis after every run less than maximum-run.
CORRREL - the matching package from KERN.
DEM - application program that supervises CORREL and sees to quality control.

The package is user friendly, and fits into the framework of COPS as enumerated below. A slated refinement will be to allow the operator to intervene, whenever necessary, to change either the threshold for terrain analysis or the correlation coefficient, or to make manual measurements of an area where the correlator does not perform well.

3.3 Preprocessing and Postprocessing

These are exactly as in COPS, the former involving calibration of minimum grid spacing, inputting project parameters and extraction of terrain skeleton and anomalous regions by selective sampling, while the later involves output conversion and further quality checks.

4. EXPERIMENTS

It is necessary to assess the potentials and limitations of this DTM data collection package, especially the accuracy, reliability, convenience of operation and gross-error detection ability, in order to justify further investment in its development. Wide angle photographs at 1:5500 (flying height (H) is approximately 825 meters) of Echellens in the South of France were used for these tests. The diapositives were 5 years old and on visual inspection did not suggest a high image quality. The threshold for acceptance of digital image matching was set (except when otherwise stated) at the normalised value of 0.40. A qualitative classification of the images based on visual interpretation is used as follows:

Image Signal Variation (Texture) Classification: In descending order of suitability for digital image matching, 4 classes were distinguished, ranging from excellent to poor.

Terrain Classification: In ascending order, the terrain roughness was classified into 4 categories, ranging from smooth to rugged.

4.1 Experiments on Precision or speed

In order to find the accuracy obtainable with PS-DEMZ on areas of differing texture and terrain roughness, measurements were made in selected patches of 32m by 32m, and checked on manually measured data using COPS. In an area of flat terrain and good texture, there were no failures and only 5 heights were in error greater than 0.500 meters. Time efficiency was as good as could be obtained from COPS, probably because the good texture of the image ensured that successful matches were obtained from early attempts. The root-mean-square measuring accuracy (RMSE) of all measured points when checked on the manual measurement is 0.23 meters. When the error of manual measurement is taken into account, RMSE is reduced to 0.22 meters (0.027% of H). The time per point is a pointer to difficulties in matching, which is corroborated by the measuring accuracy. See Table 1 below for all the results. The mean of discrepancies tended towards zero, suggesting that the errors were not systematic.

4.2 Experiment on thresholding

For this experiment, it was assumed that a DTM should be produced with a standard error not larger than 0.3m.

i) A patch of fair texture was selected, with minimum sampling interval set to 4 meters which corresponds to the matching window size to avoid correlated values of the output DTM. Varying values of the threshold were used to sample the same terrain relief. Then those points not measured were interpolated using simple linear interpolation to form a regular grid; the later was checked on another DTM-set that was measured manually with the COPS package.
ii) The same experiment was performed again, but this time with manual measurements. Thus different threshold values were used for sampling. Later the points not measured were interpolated to form a regular grid, and checked against manually measured regular grid.

A plot was made from the results to aid comparison and also to possibly determine optimum threshold values from it to suit various precision requirements (see figures 1 and 2). Based on this very limited experiment, it would seem that the threshold for PS-DEMZ should not be much larger than the one that would be used for manual PS. A value even smaller than 2.5 times the measuring precision of the VLL method seems advisable, considering both the number of points measured and the RMSE achieved.

4.3 Experiments on error detection.

By chance, the sampling pattern was so fortunate that no matches occurred on top of buildings though the software retains routines for their possible occurrence. Further tests are needed to verify their effectiveness.

St. = RMSE (correlator + manual).
Sc. = RMSE (correlator only).
Tpp = Time per point in seconds.
Fr = Failure rate = failures / total no of points measured * 100.
Time per point for COPS (PS only) is 2 seconds.

terrain type	texture	no of pts.	RMSE st.	RMSE Sc.	% of H	Tpp (secs.)	Fr
smooth	v.good	92	0.23	0.22	0.027	2	0%
sl.rgh	fair	223	0.42	0.41	0.050	4.5	7%
fai.rgh	good	288	0.34	0.34	0.040	3.5	5%

Table 1: Performance of PS-DEMZ DTM collection program.

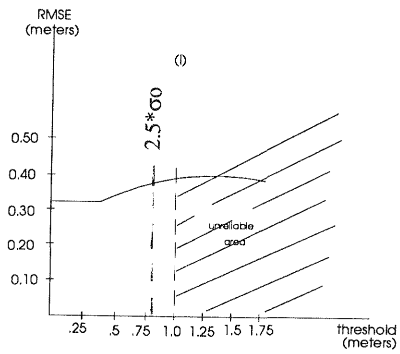

Figure 1: Effect of thresholding in the manual measurement system.

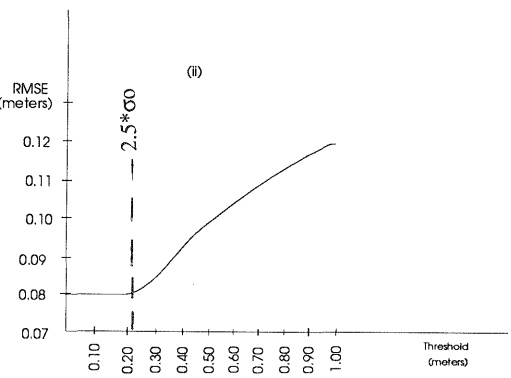

Figure 2: Effect of thresholding in the VLL system.

5. CONCLUSIONS and RECOMMENDATIONS

1) Approximate heights are important when the VLL-concept is applied because a close approximate height ensures a good pull-in of the images during matching. Apart from reducing failures, it saves time when there is a match, due to lesser computations.

2) DTM acquisition using this VLL system by progressive sampling offers very good performance when the image quality (resolution, signal variation and contrast) is good enough and terrain is not rough, without occlusions and obstacles (no failures, $\sigma o < 0.03\%$**H**, 2 seconds per point). Further experiments, however, will be done to validate that this is generally true.

3) Since a failure free DTM data collection cannot be attained yet by digital matching only, especially for large scales, attention should be given to good supervision of matching, reduction of the avoidable failures and optimum operator intervention. The main source of failures in digital image matching is poor image contents, especially when combined with geometric distortion caused by steep terrain slopes. Segmentation of images to divide processing between manual (with some computer support) and automatic operation would help to achieve high performance. Composite Sampling is a practicable approach to comprehensiveness and progressive sampling could avoid problematic areas.

4) Threshold specification requires further investigations. Considering the dependency of the 2nd differences on measuring precision only, a value smaller than $2.5*\sigma o$ (σo=0.035%-0.07% of H) can be used.

5) Poor image contents account for most erroneous matches. The tolerance for picking suspicious matches should decrease progressively with increasing runs.

6) Since selective sampling acquires the relief skeleton, areas with steep slopes and breaklines may be segmented and classified so that predicted values will be used in place of measured ones in case of correlation failure.

7) PS-DEMZ is not tedious like manual COPS, though cannot yet match the later's precision due to short-comings of its DIM algorithm. It is better supervised, more reliable, more convenient in operation and, therefore, out-performs CORREL.

Future work: A better digital image matching algorithm should be implemented in place of VLL, to automate Progressive Sampling in near real time. It is probably the greatest short-coming of this package. Experimental investigations shall continue in order to establish operational procedures. That misleading correlation on top of buildings could be checked when measured values are higher than predicted by a selected threshold needs to be investigated with appropriate data sets.

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