DTM GENERATION FROM RUSSIAN TK-350 SPACE IMAGERY IN THE PC-BASED PHOTOGRAMMETRIC SYSTEM Z-SPACE

Alexander SIBIRYAKOV
State Research Institute of Aviation Systems (GosNIIAS), Moscow, Russia
sibiryakov@mtu-net.ru

Working Group IC-15

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ABSTRACT

The paper describes a number of methods for fast DTM generation, processing and merging implemented in the new powerful PC-based photogrammetric system Z-Space, which is specially optimized for TK-350 imagery. The particularity of DTM processing for TK-350 imagery consists in large amount of DTM points; it is usually equal to tens millions. The developed DTM generation method uses terrain and image pyramids to produce a dense disparity map with resolution up to one pixel. The matching speed achieves 1500 image points per second on ordinary computers such as IBM PC with Pentium 200MHz. The high matching speed is reached by prediction from a DTM pyramid with the help of a geomorphologic map. The regular DTM matrix is produced in geodesic northing - easting coordinates system by fast bilinear interpolation of 3D points. The speed of full DTM generation process achieves 700 DTM points per second. To produce very large DTM limited only by available hard drive space a procedure for merging of overlapped DTMs is developed. The accuracy of the DTM is measured in ground control points. The typical error variance is 10m in height.

1. INTRODUCTION

DTM generation from a stereopair of images is a basic problem solved on digital photogrammetric systems. Since the Russian space images obtained by the TK-350 camera became available in the world market the possibility to create a DTM on large territories has appeared. Each such image covers an area of 200 km by 300 km with a resolution about 10 meters [SPIN-2]. The sequence of images produce true stereopairs with 80 % overlap that allows to create a DTM on territory up to 160 km by 300 km with an accuracy of 10m using the only stereopair.

For this purpose, the full-functional digital photogrammetric system called *Z-Space* was created. The system includes modules for mono- and stereo-visualization, interior, relative and exterior orientation, epipolar rectification of images, DTM, orthophoto, and vector objects creation. The system is intended for work both with space and with aerial images, however optimization of its work was carried out especially for the TK-350 images. The paper is devoted to algorithms of DTM generation, processing, and merging implemented in last version 2.0 of Z-Space system.

2. DTM GENERATION IN ONE LEVEL OF THE DTM PYRAMID

Characteristic features of the developed matching method are: 1) preliminary image analysis for informative templates detection; 2) the use of rectangular search areas that allows not performing preliminary epipolar rectification of images (that is especially important in case of large sizes of TK-350 images); 3) the use of image pyramids for magnification of computational speed and for more reliable matching. Optimal number of pyramid levels is calculated from search areas sizes.

2.1 Informative image fragments

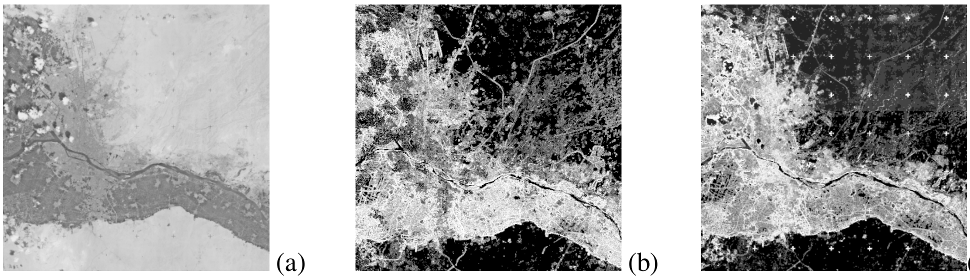
A template can be selected in any place of image overlapping area. Informative templates found on the left image are used for matching. The unsuccessful choice of templates can cause false matches. It happens if to locate the template in area occluded on the other image or in area with periodic texture or in area with a low signal. Last case meets most frequently in work with space images.

At use of correlation methods, a correlation coefficient is the best characteristic of a signal level inside a template. On Fig.1(b) the correlation coefficient obtained during space images matching is shown as grayscale image. It is visible, that the correlation coefficient completely reflects a signal level inside templates. The templates with a small variation of brightness (desert, river) have low correlation coefficient. On the contrary, the most informative templates (urban part, road, and the shores of the river) have high correlation coefficient. The disadvantage of this characteristic that it is calculated during matching, while the index of signal level should be calculated before matching, indicating on those templates, which will have accurate matching.

In the developed method a variance of template brightness is used as a priori evaluation of a signal level. From a comparison Fig.1(b) and Fig.1(c) it is visible, that brightness variance is rather informative index which is similar to the correlation coefficient. An advantage of this index is that it is calculated prior to the beginning of the matching. We develop a statistical criterion of a signal level in the template [see Sibiryakov, 1998] that has an aspect: if

$$\sigma \geq (1+\alpha_p / \sqrt{2(N-1)})\sigma(u) \tag{1}$$

then the template is considered uninformative and the matching is not produced. Here σ - template brightness variance, N - amount of pixels in the template, α_p - quantile of the normal distribution; $\sigma(u)$ - dependence of noise variance from a brightness, which in case of TK-350 images is shown on Fig.2.



(a) (b) (c)

Figure 1. A priori and a posteriori evaluations of signal level inside templates. (a) Original image (left image of the stereopair). (b) Correlation coefficient as a posteriori evaluation of a signal level inside templates (the coefficient values from [0,1] are transformed to the gray-level range [0,255]). (c) A variance of a template brightness as a priori evaluation of a signal level inside templates (variance values are transformed to the gray-level range [0,255]).

Criterion (1) allows deciding: 1) whether the given template has sufficient signal level; 2) if the template is not informative, whether it is possible to change it sizes so that it has become informative. For this purpose the algorithmic procedure based on checking criterion (1) at magnification of template size up to some maximum size is developed.

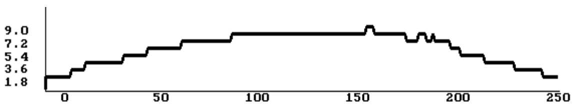


Figure 2. Dependence of noise variance from brightness for TK-350 images.

2.2 Point matching using image pyramid

The cross-correlation matching method with using of image pyramids is developed. The application of a image pyramid has two basic purposes: 1) reduction of computation time; 2) definition of more accurate initial approximations for lower levels processing by results of top levels processing (search area reduction). The method is based on searching of correlation coefficient maximum

$$k(a,b) = \left(\sum_{(x,y)} f(x,y)g(x+a,y+b) - N\bar{f}\bar{g} \right) \Big/ \left(\sigma_f \sum_{(x,y)} g^2(x+a,y+b) - N\bar{g}^2)^{1/2} \right) \tag{2}$$

where a,b - shift parameters between the template $f(x,y)$ and corresponding right image fragment $g(x+a,y+b)$; $\bar{f}, \bar{g}$ - average brightness of appropriate fragments, σ_f - variance of template brightness used at an evaluation of the signal level criterion (1).

For each template selected on the left image matching problems (3) are solved at all levels of the pyramid.

$$(a^*, b^*)_i = \arg\max_{a,b \in R_i} k(a,b)\ ,\ i = n_{max},...,1 \tag{3}$$

Here R_i is a rectangular range of shift parameters at a level i. Problems (3) are solved by sequential search of shift values from a possible range. Then the subpixel improvement of this solution by evaluation of correlation function barycentre coordinates in a neighborhood it of the maximum is applied. Only the points with high correlation participate in the subpixel improvement. The computation time of algorithm resolving problem (3) depends on search area sizes. For reaching computing effectiveness it is necessary to select an initial level of a pyramid automatically in dependence on search area sizes.

Let

$$R = \{\ (a,b)\text{: } a_{min} < a < a_{max}\ ;\ b_{min} < \ b < b_{max}\ \} \tag{4}$$

be a rectangular search area on the right image. On an n-th level of the pyramid the search area looks like (5). Suppose on n-th level the shifts $(a^*,b^*)_n \in R_n$ are found. Then the search area on n-1-th level looks like (6), where Δ_a, Δ_b are expansions of a search area at detail levels of the pyramid

$$R_n = \left\{(a,b): 2^{-n+1} a_{\min} \le a \le 2^{-n+1} a_{\max}, 2^{-n+1} b_{\min} \le b \le 2^{-n+1} b_{\max}\right\} \tag{5}$$

$$R_{n-1} = \left\{(a,b): 2a_n^{**} - \Delta_a \le a \le 2a_a^{**} + \Delta_a, 2b_n^{**} - \Delta_b \le b \le 2b_n^{**} + \Delta_b\right\} \tag{6}$$

As the horizontal size of a search area is usually more then vertical size, the optimum pyramid level is calculated from the condition of minimization the sum of all search areas:

$$n_{opt} = 1 + \left[\log_2 \frac{a_{\max} - a_{\min} + 1}{2\Delta_a + 1}\right] \tag{7}$$

2.3 Regular matrix creation

After solving problem (3) for all templates the regular matrix of the identified points is obtained (see Fig.3(a)). Some knots of this matrix have not values because appropriate templates do not satisfy to criterion (1) or correlation coefficient less then specific threshold. The values in empty knots *(i,j)* are interpolated by the inverse distance weighting [Shepard, 1964].

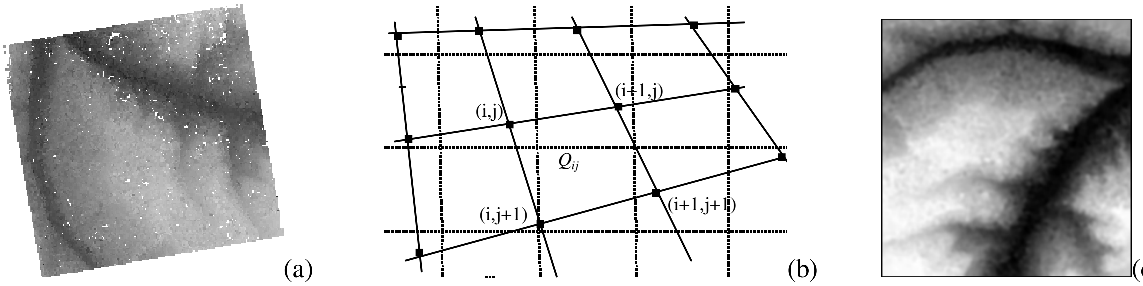


Figure 3. Regular DTM matrix creation. (a) Regular matrix of horizontal disparities (values are transformed into the brightness range 0..255). (b) This figure schematically shows a disposition of matched points projected in object space. The dashed lines show a regular DTM matrix that should be obtained from known 3D-points. The coordinate axes are oriented along geodesic axes. (c) Result of the regular DTM matrix creation (height values are transformed to the brightness range 0..255).

DTM representation as a regular grid in the geodesic easting-northing coordinates is adopted in the system. After matching and interpolation of disparities, a set of correspondent points is obtained. Coordinates of 3D-scene points are calculated under the photogrammetric formulas with allowance for known orientation parameters. By $H^*=\{ (X,Y,Z)_{ij}, i=1,...,M_x, j=1,...,M_y \}$ denote the set of 3D-points. Points in H^* are distributed as a structure topologically equivalent to square grid (Fig.3(b)). By $H = \{H(m,n),\ m=1,...,N_x,\ n=1,...,N_y\ \}$ denote a final DTM representing regular matrix by a size N_x by N_y (Fig.3(c)). For brevity $H(m,n)$ we shall designate as H_{mn}. Coordinates (X,Y) of a DTM's knot (m,n) are determined by a resolution S and coordinates of the upper left corner of the matrix by the following way: $(X(m,n),Y(m,n)) = (X_0 + mS,\ Y_0 + nS)$.

For each (i,j) , $i=1,...,M_x-1,\ j=1,...,M_y-1$ consider a quadrangle Q_{ij} on the plane (X,Y) with vertexes in knots (i,j), $(i+1,j)$, $(i,j+1)$, $(i+1,j+1)$ (see Fig.3(b)). Height value H_{mn} of knot $(X(m,n),Y(m,n))$ belonging to Q_{ij} are obtained by a bilinear interpolation of values $Z_{ij}, Z_{i+1j}, Z_{ij+1}, Z_{i+1j+1}$.

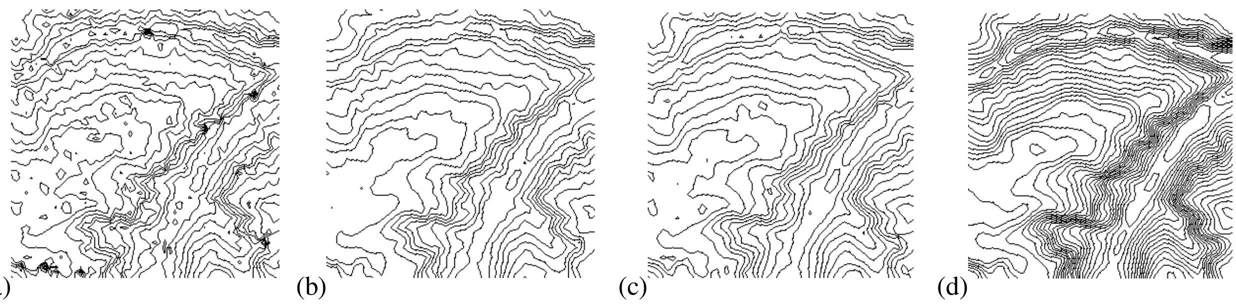
2.4 DTM filtering and smoothing

An automatically generated DTM as a rule requires post processing. The reasons are: 1) the matching algorithm produces false correspondent points; 2) point coordinates are calculated or interpolated with some error; 3) there are correctly matched points not belonging to an underlying surface, having own characteristic height (trees, houses). In all cases, the fulfillment and correction of height values should be provided. The algorithmic procedures of height outliers identification and replacement by more probable values were developed for the automatic correction. The joint application of filtration and smoothing procedures allows achieving a required degree of a surface smoothness that is important at construction of "good-looking" relief contours. The developed methods of a DTM filtration and smoothing are briefly circumscribed below. The results of these methods application are shown on Fig.4. For obviousness a DTM with many outliers was generated (Fig.4(a)).

Rank-based filtering. For each DTM knot (m,n) a neighborhood $R_s(m,n)$ of sizes s by s is considered. The variational series of values H_{kl} inside $R_s(m,n)$: $H_{(1)} \le H_{(2)} \le ... \le H_{(s^2)}$. is made. If H_{mn} is the first or last term of this series ($H_{mn} = H_{(1)}$ or $H_{mn} = H_{(s^2)}$) it is substituted with a median $H_{(s^2/2)}$ of the series.

Bicubic σ-filtering. The given filter is smoothing. For each DTM knot (m,n) a neighborhood $R_s(m,n)$ of sizes s by s is considered. The DTM in the neighborhood is approximated by a bicubic surface $z(x,y)=a_0+a_1x+a_2y+a_3x^2+a_4xy+a_5y^2+a_6x^3+a_7x^2y+a_8xy^2+a_9y^3$. The coefficients a_k are calculated by the least squares method using values H_{kl} from $R_s(m,n)$. Then average Δ and variance σ of a deviation of a DTM from the bicubic surface are calculated. If $H_{mn} < \Delta - \alpha\sigma$ or $\Delta + \alpha\sigma < H_{mn}$, i.e. the deviation from the bicubic surface in a knot (m,n) lies outside of an admissible interval, which is inspected by the parameter α, the value H_{mn} is substituted with a value of a bicubic surface $z(0,0)$.

Spline smoothing. In the given method the surface that minimizes a quadratic variation, is selected as a smoothing surface [Grimson, 1983]. After transformation to discrete domain and grouping terms the quadratic variation has an aspect of the quadratic form; the minimization is performed by an iterative gradient projection method.



(a) (b) (c) (d)

Figure 4. DTM filtering and smoothing. (a) Original DTM with many outliers; (b) Rank-based filtering, 5 iterations; (c) Bicubic - σ-filtering, α=1; (d) Spline smoothing, 5 iterations

3. USING THE GEOMORPHOLOGIC STRUCTURE OF THE DTM

3.1 Geomorphologic map generation

Each terrain has the unique geomorphologic features, for example tops of mountains and hills, mountain edges and other singularities of a relief (Fig.5(a)). The procedures of DTM processing should take into account these features to not introduce essential distortions in a DTM.

The given section is devoted to a new effective method of the DTM automatic analysis realized in the system. The method permits to classify 1) singular points (tops and hollows); 2) special lines (watershed lines, gorges, breaklines); 3) areas of a small surface variability (flats, slopes).

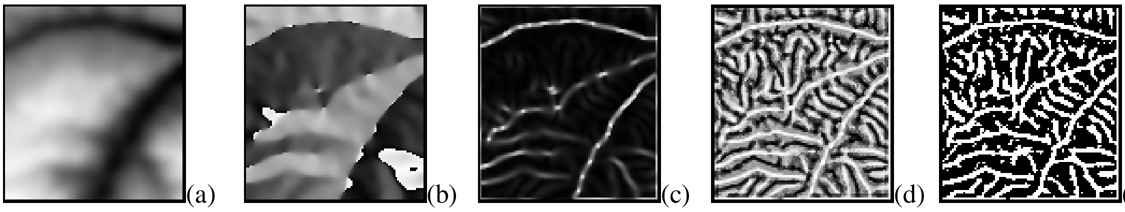
The method is based on study of a scatter of gradient directions in each point of a smoothed surface. As a measure of a scatter, a variance of a gradient direction in the neighborhood of each point is adopted. Intuitively it is clear, that in the neighborhood of a singular point the gradients have different directions therefore variance should be large. In the neighborhood of a special line, the gradients have two directions (to opposite sides from a line). In the region of a small surface variability, the gradient direction variance should be small.

In each DTM point (m,n) the gradient direction $\alpha(m,n)$ is calculated and is transformed to the range $[0,2\pi)$ (Fig.5(b)). On this figure all surface singularities such as singular points and lines, areas of a small surface variability are visible. For quantitative expression of surface singularities a variance of gradient direction in a neighborhood 3x3 of each point is calculated:

$$\sigma_1(m,n)=\sqrt{\frac{1}{8}\sum_{i=-1}^{1}\sum_{j=-1}^{1}\alpha^2(m+i,n+j)-\frac{9}{8}\overline{\alpha}_1^{\,2}(m,n)},\quad \overline{\alpha}_1(m,n)=\frac{1}{9}\sum_{i=-1}^{1}\sum_{j=-1}^{1}\alpha(m+i,n+j) \tag{8}$$

As the angular magnitudes have the period 2π these formulas can give an overstated variance. Therefore, the second evaluation of variance σ_2 is calculated for angles shifted on $\overline{\alpha}_1$ and transformed to the range $[0,2\pi)$. Least estimation $\sigma = min\{\sigma_1, \sigma_2\}$ is considered as a true value of variance. From the analysis of Fig.5(c) it is visible that $\sigma(m,n)$ can serve as a *geomorphologic map* of a DTM. The singular points have value of σ accepting a local maximum. The special lines have the appropriate form on a geomorphologic map. The areas of a small surface variability have a small value of σ.

Singular points detection is possible by thresholding a value of σ or by local maximum searching. The special lines can have different values of σ so they cannot be located by simple thresholding technique. Therefore a normalization of a geomorphologic map for deriving a special *geomorphologic index I(m,n)* is necessary. In an outcome of a research, the rather effective method of normalization was found. The method consists in determination a rank in a small neighborhood of each value of a geomorphologic map: $I(m,n)=rank\{\sigma(m+i,n+j)\}$. The result of such procedure is shown on Fig.5(d). It is visible that singular points and special lines have a high rank; the areas of a small surface variability have a low rank. Therefore, some threshold T_1 can do the separation (Fig.5(e)).



(a) (b) (c) (d) (e)

Figure 5. A DTM geomorphologic map generation. (a) Test DTM; (b) Gradient directions (the values α from $[0,2\pi)$ are transformed to the brightness range 0.. 255); (c)Geomorphologic map (the values σ from $[0,2\pi)$ are transformed to the brightness range 0.. 255); (d) Rank-based normalization of the geomorphologic map. The neighborhood used is 5x5 knots (the values $I(m,n)$ from 1 up to 25 are transformed to the range 0.. 255); (e) An example of classification of the geomorphologic index $I(m,n)$ by threshold $T_1 = 13$.

3.2 Using geomorphologic prediction in hierarchical DTM generation

The matching method described in Section 2 uses rectangular search areas. Search area sizes are evaluated with the help of a height range, in which all height values of the DTM should be. Such evaluation is made approximately either with the help of maps, or with the help of stereo-measurements. Usually the height range is a constant for all points to be matched.

The use of constant search area sizes is certainly ineffective in regions of a small surface variability. In such regions the searching is performed on large areas while disparities have close values. Therefore, a local estimation of search area sizes for each template is necessary. For this purpose the hierarchical scheme of DTM generation was developed. At this scheme, DTMs with a different resolution are generated sequentially. Each DTM serves for a local evaluation of search area sizes for next DTM generation (Fig.6). The choice of such scheme was determined by the following reasons:

Minimum interference of an operator in DTM generation process. The operator selects only resolutions of an initial and detail DTMs; the remaining steps are performed automatically. If on any step the obtained DTM contains noticeable errors, which cannot be corrected automatically, the operator can correct them manually.

Robustness to false matches. Geomorphologic features of a DTM are evaluated locally using initial DTM. This information is used for evaluation of search areas during detail DTM generation. This considerably reduces errors originating when the local geomorphologic features are not known beforehand.

Simple interpolation. There is no necessity to use the time-consuming inverse distance weighting interpolation during detail DTM generation. Instead of using this method, values in empty knots are obtained by fast bilinear interpolation of knots of an initial DTM.

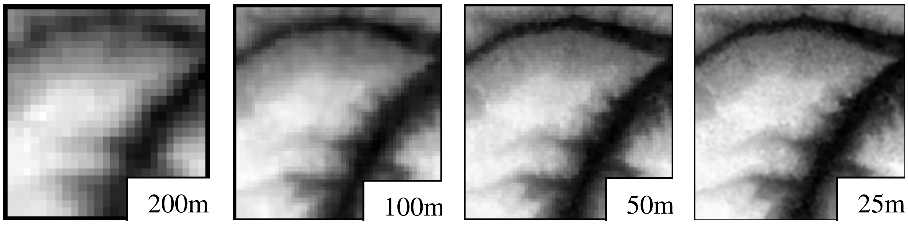


Figure 6. Hierarchical scheme of DTM generation. The DTM pyramid and resolutions at appropriate levels are shown.

By $H_N(m,n)$ denote a height value in a (m,n)-th knot of a DTM in N-th DTM pyramid level. Let it is necessary to generate a detail DTM $H_{N-1}(m,n)$ with a resolution s times finer. Obviously that $H_{N-1}(sm,sn) = H_N(m,n)$. By the help of H_N it is possible to evaluate a probable range for a value $H_{N-1}(sm+i,sn+j)$, $i,j = 1,\ldots,s-1$ by the following way:

$$min\{H^*_{m,n},H^*_{m+1,n},H^*_{m,n+1},H^*_{m+1,n+1}\}<H(sm+i,sn+j)<max\{H^*_{m,n},H^*_{m+1,n},H^*_{m,n+1},H^*_{m+1,n+1}\}. \qquad (9)$$

Here H^*_{mn} is heuristic evaluation of a height obtained with the help of height values and partial derivatives in a knot (m,n), and also with the help of geomorphologic index:

$$H^*_{mn} = H_N(m,n) + \frac{I(m,n)}{T_2}\ (2H_N(m,n) - H_N(m-1,n) - H_N(m,n-1)) \qquad (10)$$

$$H^*_{m+1,n} = H_N(m+1,n) + \frac{I(m+1,n)}{T_2}\ (2H_N(m+1,n) - H_N(m+2,n) - H_N(m,n-1))$$

For an evaluation $H^*_{m,n+1}$, $H^*_{m+1,n+1}$ the similar formulas with an appropriate replacement of partial derivatives are used. Here the heuristic parameter T_2 controls the influence of geomorphologic map on a probable height range (Fig.7).

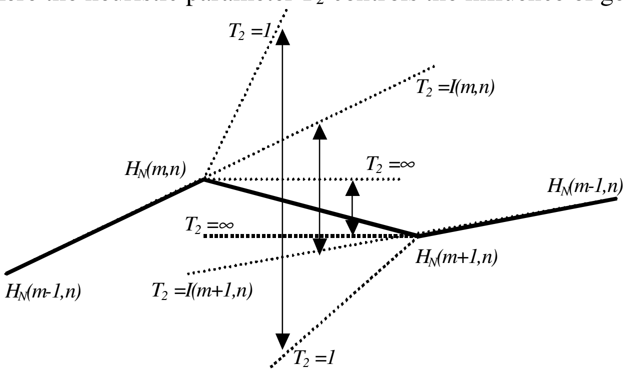


Figure 7. Evaluation of an altitude range on an interval *(m,n)-(m+1,n)* with the help of geomorphologic index. The thick line shows a DTM profile. The dashed lines show values H^*_{mn} and $H^*_{m+1,n}$, obtained from (10). As examples three values of the parameter T_2 are taken. The arrows show appropriate evaluations of an altitude range obtained from (9).

Using the photogrammetric formulas, the height range (9) is transformed to a disparity range. This disparity range determines a search area for the templates, which centres lie inside a quadrangle formed by projection of knots *(m,n), (m+1,n), (m,n+1),(m+1,n+1)* of rough DTM. The obtained search areas are equal to several pixels; there are on the order less then search areas obtained only from rough height range. A matching time accordingly decreases during detail DTM generation.

3.3 Setting strategies for DTM generation

The developed method of a DTM generation allows effectively taking into account characteristic areas of a terrain. A terrain can have the following characteristic areas: 1) areas of strong variability (mountain regions); 2) areas of an average variability (hilly regions); 3) areas of a small variability (flatness); 4) areas of an equal surface (sea, lakes, reservoirs); 5) special areas defined by an operator (areas with pickets and breaklines). Such areas can be defined visually in a stereomode. For each area, the operator can set a strategy for DTM generation or select strategy defined in the system. Each strategy except for matching parameters (such as size of a correlation window, threshold on a correlation coefficient etc.) is determined by three heuristic parameters:

Characteristic distance of terrain variability. This parameter serves for resampling of a regular grid of template centres. For planes this parameter is selected large (200m-500m); for mountain regions is selected small (10m-20m).
Variability of a surface (threshold T_1 in a Fig.5(e)). This parameter determines a fraction of those points, which immediately will be transferred from N-th DTM level to $N-1$ level by bilinear interpolation.

Predictability of a surface (parameter T_2 in (16)). This parameter determines behavior of the N-1-th level surface between knots of the N-th level surface (Fig.7). In mountain areas a high variability of a height value is possible therefore given parameter is selected small. On the contrary, in areas with well predictable terrain this parameter is set large.

4. DTM MERGING

To generate a DTM of very large sizes the possibility of merging of several DTM matrices is developed (Fig.9(a)). The merged matrices can overlap each other and can have different resolution. The merging algorithm is based on weighted averaging of height values (Fig.9(b)). Suppose there are k regular DTM matrices denoted by $H_i(n,m)$, $m_1^i \le m \le m_2^i$, $n_1^i \le n \le n_2^i$, $i=1..k$. K. For each matrix a two-dimensional smooth weighting function $w_i(m,n)$ is introduced. The weighting function is equal to zero behind the boundaries of the matrix. It accepts values from 0 on the boundaries up to 1 in the centre of the matrix. The derivative of weighting function is equal to 0 in boundary knots of the matrix. The weighting function is defined as follows

$$w_i(m,n) = w\left(2\frac{m-m_1^i}{m_2^i-m_1^i}-1\right) w\left(2\frac{n-n_1^i}{n_2^i-n_1^i}-1\right), \qquad \text{where} \qquad w(x)=\begin{cases}-2|x|^3+3x^2+1, & -1\le x\le 1\\ 0, & x<-1, \quad x>1\end{cases} \tag{11}$$

Then the DTMs are merged as follows:

$$H(m,n)=\sum_{i=1}^{k} H_i(m,n)w_i(m,n) \Big/ \sum_{i=1}^{k} w_i(m,n) \tag{12}$$

The correction of original DTMs by results of merging is implemented also (Fig.9(b)). That gives elimination of boundary effects due to interpolation.

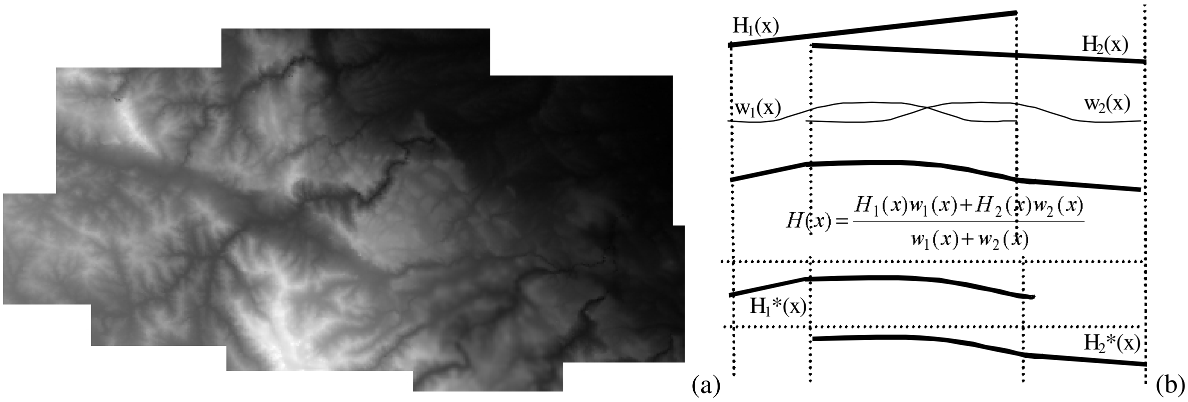


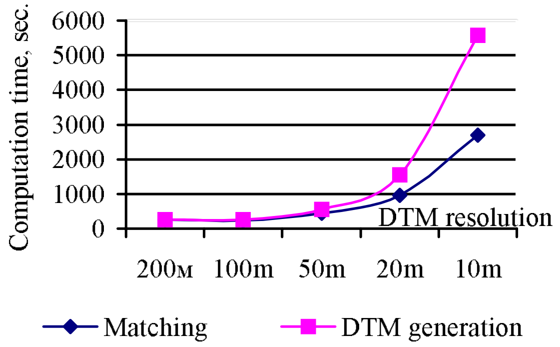
Figure 9. DTM merging. (a) Result of eight overlapped matrices with a resolution 10m merging. The resulting DTM cover region 90km by 50km with a resolution 10m. (b) Illustration of the algorithm. The profiles of two overlapped DTMs H_1, H_2, appropriate weighting functions w_1, w_2, and the result of merging H are shown. Also the results of original DTM correction H_1^*, H_2^* are shown.

5. RESULTS

In the given section, some temporal performances of the DTM generation algorithm are described. The testing was carried out on the IBM PC computer with the Pentium MMX 200MHz processor and 64 Mbytes of operative memory. In Table 1, the results of the hierarchical DTM generation method testing are presented. A DTM pyramid with an initial resolution 200m and final resolution 10m was generated. The DTM area is 20 km by 20 km. The same strategy that is used in the system by default was applied for the full DTM area. A correlation window 15x15 pixel was used. An initial evaluation of a height range was from 0 up to 3300 meters. It corresponds approximately to search area size of 300 pixels. After final DTM generation, the height range has appeared to be from 790m up to 2830m. For the obviousness matching time and DTM generation time and the appropriate computation speed are shown as the graphs in Fig.10. The full time of DTM generation includes the matching time and time of construction of a regular DTM matrix in geodesic coordinates. It is visible that beginning from some resolution (50m) generation of regular matrix contributes more and more to common time. A matching speed considerably grows due to accurate prediction of search areas.

Resolution of a DTM (m.)	Matching time (sec).	Full time of DTM generation (sec).	Amount of matched points	Amount of DTM points	Matching speed (points/sec).	DTM generation speed (points/sec)
200	252	261	9575	100x100	34	39
100	234	259	33341	200x200	142	155
50	451	552	163792	400x400	363	291
20	968	1546	103136	1000x1000	1065	648
10	2694	5582	4151427	2000x2000	1540	717

Table 1. Temporal performances of the hierarchical DTM generation method



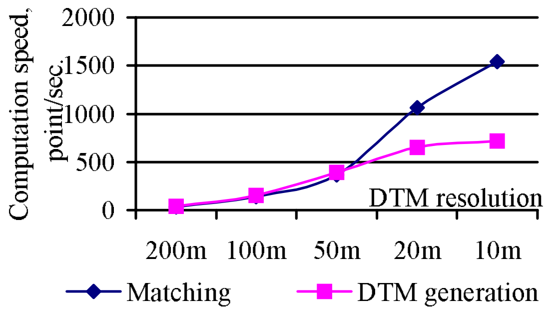


Figure 10. Temporal performances of the hierarchical DTM generation method

The DTM merging algorithm is implemented in such a manner that practically all work happens immediately to the hard drive of the computer. Therefore, size of a resulting DTM is limited only to volume of the hard drive and does not depend on operative memory size. The merging speed depends on overlapping configuration and achieves tens thousands DTM points per second.

Accuracy of a DTM is evaluated in ground control points, which were used for exterior orientation of a stereopair, or in additional points with known coordinates. Achieved variance of deviation between DTM and control points is 10m in height.

6. CONCLUSION

Today market of photogrammetric tools offers the users the diversified and high-power systems aimed at solution of a large variety of problems and embodied last progress in different areas. Nevertheless, within last years one more photogrammetric system Z-Space, oriented mainly on fast generation and processing of large DTMs from Russian space snapshots on usual personal computers, was created. Taking into account all the growing interest of the users to systems of such class is possible to hope that the system Z-Space will occupy its own place among other photogrammetric systems.

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