It is clear that a 3-parameter (x, y, and z shifts) least squares match will provide the most reliable results from rasterised data. The grid size must be very similar to the original density of the data or bias effects will become evident. These effects are significantly reduced by using planar interpolation based on a TIN of the original laser points as compared to using nearest neighbour binning. In areas with only minor height differences (up to 100m) quantisation to 8-bit does not have a significant negative effect on the quality of matching. This would usually be the case in relatively flat countries such as the Netherlands. However, in mountainous regions, or in urban areas with high-rise developments, the effects could be very significant. This would suggest that the dependant variable should be interpolated and stored at a higher level of quantisation than 8-bit, to ensure that important information is not lost and that the quality of shift estimation is as high as possible with rasterised data.

5 FUTURE WORK

It is clear that extreme care must be taken with the use of rasterised data for matching and the derivation of discrepancies between strips of laser data, particularly in terms of grid size, interpolation method, and quantisation level. However, Maas (2000) has shown that a significant improvement in the quality of matching results is possible using least squares matching directly on a TIN of laser points. The shifts thus derived will form the input into a least squares bundle block adjustment for scanning laser altimeter data. The relative discrepancies between strips and the absolute discrepancies between the laser data and the true ground data will be measured and used as observations in the adjustment that is in development. Further research is also needed into the nature and magnitude of individual point errors and this inventory will allow for their proper handling in the block adjustment.

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Z_SPACE - DIGITAL PHOTOGRAMMETRIC SYSTEM FOR RUSSIAN TK-350 IMAGES.

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ABSTRACT

Several years ago Russian images TK-350 and KVR-1000 appeared on the international market. Taken in combination, this imagery makes it possible to perform terrain mapping with 1:50000 scale and smaller. Special software was developed to process this specific type of data: Z_Space for TK-350 stereopairs processing and Orthospace for creation orthophoto from panoramic high resolution imagery KVR-1000.

Digital photogrammetric system Z_Space was mainly designed for rapid automatic generation of Digital Terrain Models (DTM) on the base of stereopairs of spaceborn or airborne images, for interactive 2D and stereo feature extraction, as well as for generation of perspective scenes including DTM and vector features. The system works on IBM PC under Windows 95, 98 or NT.

For modern digital photogrammetric systems the list of their basic functions is quite determined, therefore common items in given paper are listed in brief and only the specific features of Z_Space are considered in more details. Most of these features are due to the fact that originally the system was developed for TK-350 and MK-4. This infer taking into account complex radiometric characteristics, processing of large amounts of data with high speed and practically complete absence on images of artificial objects such as houses, bridges, road etc. Accuracy of DTM generated from TK-350 by digital photogrammertic system Z_Space is 7-10 m (RMS) in height and 15-20 m (RMS) in plane, for GPS measured ground control points - 5-7 m and 10-15 respectively. Matching speed for large DTMs (more than 1000000 points) on Pentium-200 is 700 disparity map points per second, speed of regular DTM matrix generation is 300 points per second, on Pentium-III-500 these are 3900 and 1300 points per second respectively. Another kinds of data processing are also available in the system and presented in the paper. Some possible applications of Z_Space are outlined in a short conclusion.

1. INTRODUCTION

Digital photogrammetric system Z_Space was developed as PC based application working under Windows 95, 98 or NT. Minimum hardware configuration includes Pentium-166, 32Mb of RAM, 1Gb of disk space. Z_Space uses as input stereopair of 8-bit black-white BMP digital images, camera calibration data, scanning parameters and ground control points (GCP) file. TK-350, MK-4 and airborn images are available for processing. Output data include regular elevation matrix in format Z_Space (4 bytes per digit), OSD (2 bytes per digit), ASCII, DGN or DXF; isolines and other vector lines in Z_Space vector format, ASCII, DGN or DXF. Two visualisation modes are realized to work with pair of images. In the stereopair mode the screen is devided into two parts. In the stereomode mixed image is formed in the interlace window which makes possible to see the stereo image through special glasses.

System Z_Space is intended for
- rapid generation of digital terrain model (DTM) in the form of regular matrix of elevaitions on the basis of stereopair of space or airial images;
- creation of orthoimages and orthomosaics;
- automatic, semiautomatic and manual contour creation and feature extraction;
- generation of 3D perspective scenes for raster and vector data.

2. MAIN FUNCTIONS OF Z_SPACE

2.1 Interior Orientation

Z_Space is able to treat all kinds of airial imagery fiducials and also space images TK-350 and MK-4 with special regular grid of crosses. For aerial images interior orientation is semiautomatic. Fiducials are projected on image according to passport data and the operator should only correct them.

Images TK-350 has special type of marking in the form of regular grid of crosses 45×29. Grid of crosses is used for correction of diffferent types of distortions including camera distortion, refraction of beams in atmosfere and chemical film schrinkage. The identification and marking of crosses are made automatically (Heipke, 1996), (Schickler, 1996).

2.2 Relative Orientation

Relative orientation can be made both in manual and semiautomatic modes. Markers of tie points are placed on images approximately, then adjusted by correlator with subpixel accuracy. After getting the first approximation of orientation angles all additional tie points are found automatically, if necessary.

2.3 Exterior Orientation

Exterior orientation uses the same modes for ground control points (GCP) measurements on images as relative orientation. In addition, the convenient input of GCP from ASCII file is realized here. This file contains the numbers of points, as well as their geodetic coordinates and can be cteated in any text editor. One should only mark any two points from the list on images, the full GCP list will be projected on images automatically. Then correction of markers is easily performed for all points in semiautomatic mode with subpixel accuracy. The use of ASCII file for GCP makes the process of measurements faster several times.

2.4 Aerotriangulation

Aerotriangulation module of the system includes measurements of tie and GCP points on images, block triangulation procedure and also creates output project files in Z_Space format for subsequent DTM generation and another types of data processing in Z_Space. This module has the same modes for tie and GCP measurements as those, used in relative and exterior orientation.

2.5 Epipolar Resampling

Once the exterior orientation is complete, fast epipolar rectification, removing y-parallax from the original images, can be made. For TK-350 (MK-4) the correction due to distortions and filtering of grid of crosses are also performed in image resampling. All algorithms in Z_Space, including image matching don’t need epipolar stereopair. Really it is necessary only for displaying visual stereo model. Nevertheless, if stereo model is created on original images, the system automatically removes y-parallax in the centre of screen.

2.6 Automatic DTM Generation

The main and most advanced part of the system is automatic image matching for 3-D reconstruction of DTM. In Z_Space DTM is created by group of algorithms automatically on regular geodetic grid. DTM area can be defined both in geodetic space and in image space. This rectangular area can be devided into several subareas, each having its own matching strategy inside. The main requirements to the algorithms of this group are reliability, accuracy and high speed of DTM matrix generation. The last is of special importance for data volumes exceeding 1000000 points of grid model.

For fast processing of large amount of data the original matching strategy, area based, was developped. High speed of DTM generation is achieved by using of
- images pyramids,
- relief geomorphological index for local heights range estimation,
- various interpolation methods at different stages of matching.

The disparity maps pyramids are used to forecast both coordinates values and matching searching range at the next level. The forecasting in pyramid is based on Geomorphologic Terrain Structure Index (GTI), which classifies terrain points in accordance with local surface smoothness. GTI is calculated automatically but also can be given by the operator during of preliminary image analysis in a stereomode. In the latter case algorithm uses a number of the predetermined strategies for flat, hilly, mountainous terrain types. Among the pyramid levels and for gaps filling various kinds of interpolation are used.

Matching speed on Pentium-200 is 700 disparity map points per second, speed of regular DTM matrix generation in geodetic coordinates is 300 points per second. Subpixel accuracy of matching is based on the original subpixel optimized crosscorrelation algorithm (Zheltov, 1997).

One of specific features of TK-350 imagery is the presence of areas with low signal/noise ratio, such as disert or ocean surface. To improve the reliability of DTM generation process, a special statistical criteruim was elaborated. This criteruim characterizes stohastic noises of camera TK-350 and distinguishes patch of image with valuable signal from pure noisy patch. The signal/noise analysis is preceeding to image matching and in case of noisy images speeds up the process greatly , because direct processing of such areas requires from correlator considerable amount of time, finally giving improper results. Another criterum of the DTM point quality is coefficient of correlation from the identidication procedure. Height values in points with law criterum value are estimated from nonlinear interpolation.

For very large DTMs (more than 3000000 points) Z_Space uses the algorithm of merging several matrices, maybe of different space resolution, with automatic heights equilizing in the overlapping area (Fig.1).

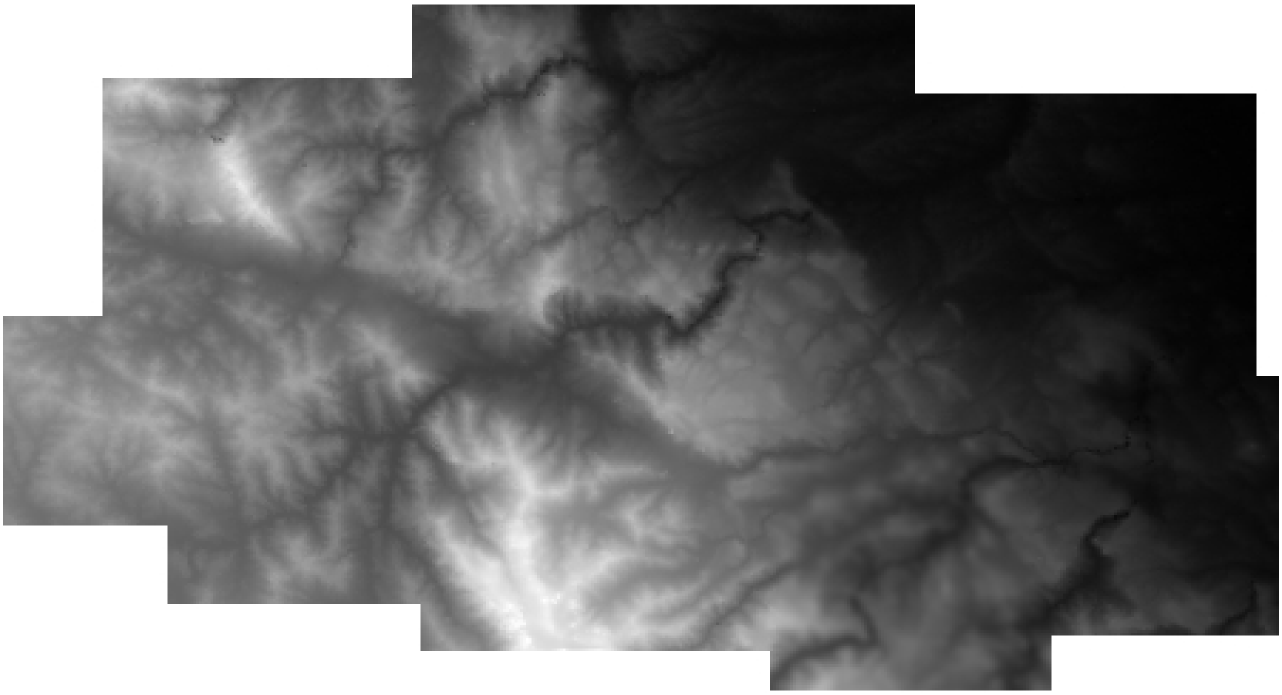


Figure 1. DTM merging. Result of eight overlapped matrices with a resolution 10m merging. The resulting DTM covers region 90km by 50km with a resolution 10m.

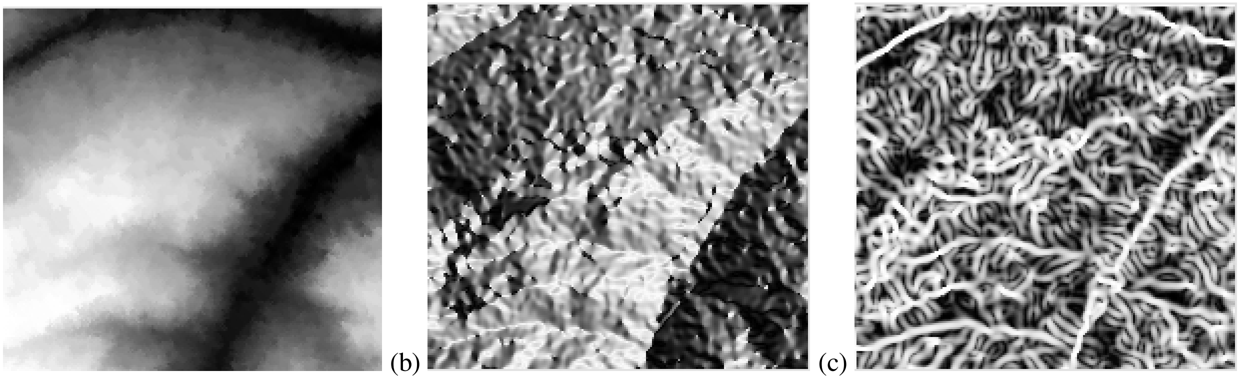
2.7 2D DTM Vizualization

Z_Space uses 2D tools for vizualisation of DTM and vector features as the most compact and flexible drawing tools. Raster DTM-image is formed on the basis of height matrix, or direction of reflected light beam at every surface point, or relief surface gradients etc. In Z_Space the following three DTM-image types are presented:

- *greyscale* use 256 levels of grey to show full heights range. As raster image it can be scaled, filtered and subjected to brightness histogram transformations;

- *shaded relief* is a conventional relief representation, lightened by parllel beam. It allows to see easily the directions of DTM surfaces;

- *morphological map* enables to reveal characteristic lines and specific points of the relief such as mountain peaks, ridges, rivers etc.



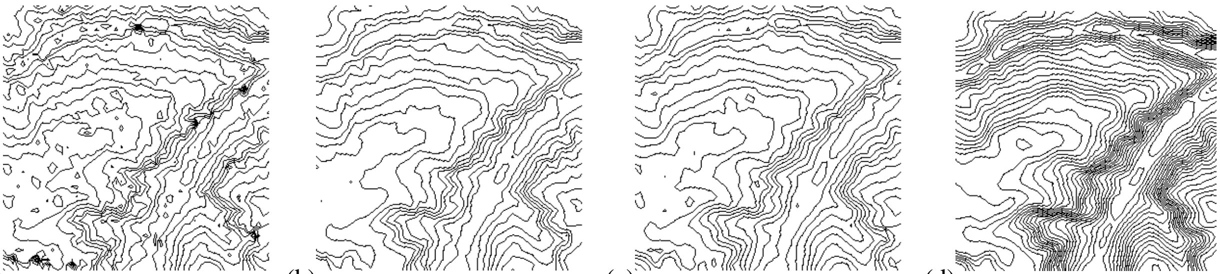
(a) (b) (c)

Figure 2. Raster DTM vizualisation: (a) greyscale image; (b) shaded relief; (c) morphological map.

For all three DTM-image types imposing of contours including the active ones is available. In Z_Space the so called active contours are used setting matching strategies, local DTM automatic postprocessing and interactive DTM editing.

2.8 Automatic DTM Postprocessing

Automatic DTM postprocessing includes a set of tools which removes blunders, fills missing height values and smoothes the relief surface if necessary. All procedures can be fulfilled both for total DTM and locally inside polygons, outlined by the user. Blunders detection is based on rank filtering or on applying Gauss criterium to height samples formed by moving window (bicubic σ-filtering). To fill missing height values different approximation approaches are used by different postprocessing procedures. These are bilinear and bicubic interpolation, inverse distance weighting (Shepard, 1964), Delaunay triangulation. Smoothing uses method that minimizes quadratic variation of surface (Grimson, 1983). Minimization is performed by an iterative gradient projection method.



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

Figure 3. DTM filtering and smoothing: (a) Original DTM with outliers; (b) Rank-based filtering, 5 iterations; (c) Bicubic σ-filtering, α=1; (d) Spline smoothing, 5 iterations

For fine DTM correction the iterative orthophoto refinement is used. This algorithm is based on DTM correction by stereopair of orthophotos from left and right images (Schenk, 1989).

2.9 Interactive DTM Editing

Interactive editing is performed in stereo. DTM in the form of contours or grid of nodes is compared with stereomodel of the site, then some corrections can be made, if necessary. Z_Space has the following interactive editing tools.

Point editing allows to change the height of every point in DTM. Used for detailed editing operations.

Editing by vector features force DTM to conform to some linear features, such as picks, ridges and rivers. This is the most powerful and universal tool for editing of very large matrices.

Area editing changes all heights within outlined polygonal areas. Possible are the following functions:
- *constant filling* makes all DTM points within polygon to get the same height;
- *plane filling* sets all points wthin area to lie on a plane determined by best fit to perimeter points;
- *triangulation* used to fill areas obscured by clouds. Delaunay triangulation is made on perimeter points and some points inside area, if any;

- *interpolation* by inverse distance Shepard algorithm is made on perimeter points fill area inside;
- *bias* moves all points inside the area up or down by a given height.

For all types of interactive editing automatic positioning of stereocursor on the relief surface is available. The special type of nadir geometry matching was elaborated to simulate actions of human operator, who moves cursor vertically up and down w hen placing it on the stereomodel surface.

The relulting DTM can be exported in OSD, ASCII, DGN and DXF formats.

2.10 Orthoimage Creation

Orthophoto is created from one of the stereopair images and DTM obtained. Some tools for features creating and editing are also available. Features created in stereo, can be imposed on orthoimage and conversely.

2.11 Orthomosaic

A seamless mosaic orthoimage is created in module SPMosaic after separate orthoimages have been obtained for the block area to be covered. The correct merging of orthoimages is based on geodetic coordinates, taken from DTMs. Equlizing of intensity histograms for separate images is performed both interactively and automatically. Radiometric corrections along the seamlines of overlapping regions are made automatically. Images of different resolutions are also merged, the highest resolution is set for resulting mosaic.

Figure 4. Region of Middle Russia.

2.12 Contour Creation

Contour lines are created in automatic, semiautomatic and manual modes. Profile relief contours are constructed automatically. Feature extraction can be done on the stereomodel, orthophoto and any Z_Space 2D-maps, described above. Vector features such as points, polylines and polygons are created and edited manually. The same features types can be treated semiautomatically if automatic positioning of stereocursor on the relief surface is used. In this case one should only move cursor along the feature line and press mouse button.
All vector features can be exported in ASCII, DGN and DXF formats.

3. 3D-VISUALIZATION MODULE

For three-dimensional DTM surface visualisation Z_Space uses module SRViewer, which enables:
- to view the terrain from any position under any angle;
- to use one of four offered surface models (frame, "plaster", coloured, textural) for visualisation;
- to create a synthesized surface image, simulating illumination from three kinds of light sources (diffuse, point, parallel);
- to construct and display the DTM profile lines;
- to make interactive measurements of surface points' geodetic coordinates;
- to visualize vector objects having been created in Z_Space.

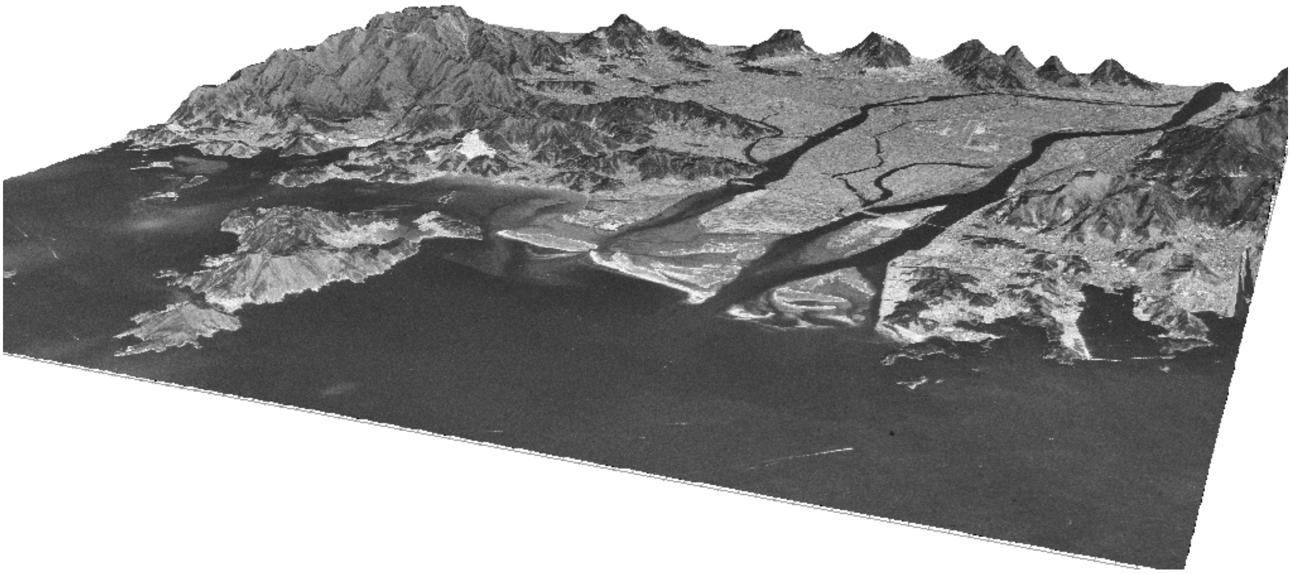


Figure 5. Pusan, South Korea.

4. CONCLUSIONS

Digital photogrammetric system Z_Space was developped primarily to create DTMs and orthoimages for vast areas. Matching speed for large DTMs (more than 1000000 points) on Pentium-200, RAM=64Mb is 700 disparity map points per second, speed of regular DTM matrix generation in geodetic coordinates is 300 points per second. The same speeds on Pentium-III-500, RAM=512Mb achived 3900 and 1300 points per second respectively. Accuracy of DTM obtained from TK-350 is 7-10 meters (RMS) in height and 15-20 meters (RMS) in plane, for GPS measured ground control points - 5-7 and 10-15 meters respectively (groung sample distance of TK-350 digital image is 10 meters). In case of aerial images the accuracy of subpixel matching is rather high (theoretically 1/5 of pixel size) and final DTM accuracy is defined primarily by the quality of GCP measurements on gr ound and their identification on images.

Automatic seamless orthomosaic provides generation of large orthoimages of high quality. In addition, contour creation procedures and feature extraction tools make it possible to obtain valuable vector data from imagery. Thus Z_Space is able to produce all basic types of photogrammetric products. These products can be exported to widely used data formats, such as OSD, ASCII, DGN, DXF.

Summarizing, we conclude that the main possible applications of the system Z_Space are:
- topographic and thematic maps updating for vast areas;
- populating GIS databases;
- creating of virtual 3D site models.

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