

JÓZEF JACHIMSKI

**VIDEO STEREO DIGITIZER
A SMALL DIGITAL STEREOFOTOGAMMETRIC WORKING STATION
FOR THE NEEDS OF SIT AND OTHER APPLICATION^{*)}**

Abstract : The Video Stereo Digitizer is a digital autograph built on the basis of a PC personal computer. It can work as a smart SIT terminal. It is suitable for plotting vector maps on the basis of pairs of monochrome or colour digital images as well as for vectorization of orthophotographs.

1. Introduction

The explosion of analytical autographs which took place at the ISPRS Congress in Helsinki in 1976 opened before photogrammetric science and practice the possibility of plotting numeric maps in real time in a continuous way. It is even possible to make use of photographs taken with nonprofessional cameras. Procedures have been developed which support the operator during plotting photographs.

However the analog nature of images made it difficult to automate the stages of plotting thus the system of an analytic autograph was supplemented with a set of television cameras and later with CCD which gave access to the image around the measuring mark in the form of an electronic signal or in digital form. This facilitated an automatic analysis of images and allowed autocorrelation procedures to be introduced.

Photogrammetry was becoming a universal, reliable and every less exclusive method owing to the computer support available to the operator during preparation and vectorization of the model.

Unfortunately the high price of analytic autographs was still making a true egalitarization of the method difficult.

Rapid development of personal computers in the late 80s was a big step on the road of reducing the elitarian nature of photogrammetry. In that time, on the basis of PC, we developed at the Department of Photogrammetry of AGH both the software for differential plotting of photographs (presented at the Congress in Kyoto) [Jachimski 1988] and the system of vectorizing the content of a photograph on the screen.

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Our investigations into vectorization of stereoscopic models on the screen of the PC monitor were outdistanced by DVP [Agnard 1988, Gagnon 1990] successfully.

A true explosion of new system for vectorization of stereograms on the screen of a computer monitor took place at the ISPRS Congress in Washington in 1992 [Klaver 1992, Miller 1992, Jachimski 1992]. Excellent and very costly systems, which-permit the screen to be simulta-neously observed by several persons, were and still are impressive. The stereoscopes used by the teams in Quebec and Cracow were replaced by oculars (eyepieces) the dynamic system Crystal Eyes and static polarizing oculars. This required, however, very costly computer solutions to be applied.

The excellent and complicated systems overshadowed the simple and cheap solutions based on the use of PC and mirror stereoscope. However it proved soon that much cheaper and simpler (and thus less perfect) systems DVP from Quebec and VSD from Cracow did not lose their popularity and that due to their price and utilization advantages they have found more and more new users and student laboratories at universities have been equipped with multistation VSD networks.

The high cost of solutions adopted by Intergraph or Leica is a consequence of the necessity to visualize on the screen of a working station alternatively the left and right image of a stereogram and to operate with the same frequency of 50 - 100 Hz the viewing system which enables selective observation of the corresponding images with the left and right eye. In 1994 the firm Galileo-Sicam in Florence and the Technical University of Torino presented a static viewing system [Dequal 1994] based on the use of two monitors observed selectively correspondingly with the left and right eye through polarizing spectrales. The Italian system is considerably cheaper and at the same time not inferior to the dynamic system.

User's interest in digital autographs has not lessened and designs based on mirror stereoscopes have been ever wider introduced. For instance the firm Leica already distributes its excellent digital working station DPW 770 (Helawy) [Leica 1994a] in its dynamic-spectrales version and in the static version equipped with a mirror stereoscope (DPW 670 [Leica 1994b]). More and more copyrighted software packages for digital autographs based on PCs and mirror stereoscopes have appeared. Thus the concept of that system does not lose its attractiveness and software solutions based on standard computers can be developed and improved without any additional cost of hardware.

Precision of plotting performed with the aid of digital autographs depends mainly on the geometrical precision and resolution of digital images. Application of very precise scanners is sometimes difficult and costly. Thus research into the accuracy of popular scanners improved by introducing suitable geometrical corrections is developing wider and wider. The readability of details is decided by the resolution of digital images. Resolution of the order of 2400 dpi or even 1200 dpi can be practically satisfactory. However plotting is often performed on images with a resolution of 600 dpi because of the still existing difficulties in storing and making accessible large files of digital images (a 230 x 230 mm photograph scanned with a resolution of 600 dpi forms a file of 30 MB or of 120 MB in the case of a resolution of 1200 dpi). However it can be expected that the fast development of exchangeable magnetic and optical-magnetic hard discs will soon lead to an easy operation of even large files containing digital images.

2.Operation principles of VSD

The Video Stereo Digitizer was built basing on the basic assumption that two digital images constituting the stereogram are visualized on the screen of the PC-SVGA monitor divided into two halves by a vertical line. The images can be watched through a mirror stereoscope placed in front of the screen [Jachimski 1994].

The cursor is animated against the background of every image using a mouse. The cursors can be moved alternately against the left and right image and their position can be recorded (image coordinate in pixels). The system is also equipped (similarly as analytic autographs) with the so called real time program which permits the fiducial coordinates to be calculated at a rate of 50 Hz for the given field coordinates of points when the orientation elements of photographs are known. The field coordinates are generated by mouse movements (DX, DY) and mouse buttons (\pm DZ) or using the keyboard. To ensure comfortable stereoscopic observation the observation parallax is being reduced during the instrument operation by automatic vertical displacements of the right image in each case when the observation parallax exceeds 4 screen pixels.

The system is equipped with a function which permits the image on the screen to be enlarged by (up to 32 times) and the stereogram content to be "drawn" (vectorized) in arbitrary enlargement.

Two subroutines operating on the digital image have been introduced: the subroutine of filtering (the F key) which causes the readability of edges in the image to be improved and the autocorrelation subroutine (the F9 key) which causes the detail in the right image to be automatically found that is indicated with the cursor in the left image (at present that autocorrelation is available only on black-white images).

The VSD system permits a vector map "drawn" on the screen to be recorded, and 7 thematical layers distinguished by bright colours against the half-tone image are being recorded simultaneously. A numerical map taken from the LIS data base can also be overlain on the screen onto half-tone images provided that every point of the numerical map has got three coordinates ascribed to them. In case of a two-dimensional data base (2D) the third coordinate can be interpolated from the numerical model measured using VSD. However the interpolation must take place outside the system (e.g. the SURFER or SCOP program). The system also allows a 2D map to be visualized again an orthophotograph (the orthophotograph is visualized on the whole screen surface). Vectorization of the content of half-tone images can be performed against the background of an orthophotograph similarly as against a stereogram and corrections to the existing numerical map can be entered.

In a typical case when orientation elements of photographs are not known it is necessary to tune them by stages.

Transformation parameters of the digital image to the fiducial system are determined in the first stage (internal orientation).

Elements of relative orientation are determined in the second stage (by measuring the y-parallaxes at Gruber points). Elements of absolute orientation are determined in the third stage basing on the controlpoints. Cursor control in the autogrammetric mode is achieved by determining the DLT coefficients basing on coordinates measured for relative orientation and on the basis of coordinates of controlpoints. In the VSD system the DLT coefficients for non-

metric photographs can be determined from at least 6 controlpoints making the second and third stage of model tuning superfluous.

3. Technical information about VSD system

3.1 Digital images

Program accepts the following formats for digital images:

1. TIFF monochromatic non-compressed (max. 256 half tone steps)
2. Indexed Colour TIFF with the palette 256 colours.
Only 248 positions in the palette will be used for digital image however, because remaining 8 colours is reserved for numerical map displaying on the screen.
3. The monochromatic pixel map format:
monochromatic format organised as a simple stream of pixels (max. 256 half tone steps).
For this format the length of line and image offset must be defined.

3.2. Hardware requirements and organisation of the disk memory

The optimum hardware it is the PC-386 with coprocessor and 4 MG RAM equipped with SVGA, mouse and mirror stereoscope on a special mount. At present the VSD can accept the following SVGA types:

- standard VESA
- cards with the graphic processors TSENG 3000 or 4000, Trident 8900 or 9000, ATI WONDER or ATI ULTRA, WESTERN DIGITAL PARADISE.

The system can be instaled on PC 286 equipped with 2 Mb RAM, but the performace of VSD in such case is lower as well as the image resolution.

The hard disc capacity should correspond to the size and number of digital images evaluated during one session (e.g. one pair of the scanned 23x23 cm aerial pictures of the 600 dpi resolution equals to 2x30 MB). The speed of data transmission from the hard disc significantly influences the respond time - during the image visualization.

The system is guided with 3-button mouse and keyboard. In the preparation stage there is a multifunctional double-mouse and P-cursor, which could be used in future instead of mouse and some keyboard functions.

The images can be visualized on the screen either with resolution 800x600 pixels (calling VSD) or 1024x768 (calling VSD H).

Before starting VSD program at least one directory devoted to the VSD program has to be created. Digital photographs can be stored in one or more directories. File *ProjectName*.PKT (described below) must be placed in the pre prepared directory which will be declared by name at the program initiation as the one accompanying restitution and plotting.

Existing vectorial maps in DXF format can be included to the project by transformation DXF format to the ABS format (specific VSD format). For such transformation special program DXF_ABS.EXE is provided.

Directory accompanying restitution and plotting contain also files produced by VSD program:

<i>ProjectName.ETK</i>	(histogram and other information about photographs)
<i>ProjectName.CFG</i>	(parameter of the project, it is: stereopaire or a single photo)
<i>ProjectName.S??</i>	(reduced size pair of photos or single photo to select the working frames)
<i>ProjectName.LU</i>	(files containing coordinates of surveyed points - binary file)
<i>ProjectName.LU1</i>	(as <i>ProjectName.LU</i> , but for the single photograph - binary file)
<i>ProjectName.OR</i>	(as <i>ProjectName.LU1</i> or <i>.ProjectName.LU</i> , but ASCII file)
<i>_OR_INT.WYN</i>	
<i>_OR_REL.WYN</i>	temporary files containing results of
<i>_OR_ABS.WYN</i>	subsequent steps of stereopair orientation
<i>_OR_DLT.WYN</i>	
<i>ProjectName.PKT</i>	preprepared ASCII data:
	- N ⁰ and coordinates of fiducials and/or reseau grid
	- N ⁰ and field coordinates of control points
<i>ProjectName.ADP</i>	parameters of distortion (by method of ORIENT)
<i>ProjectName.MAP</i>	ASCII file of map lines in the image coordinates (an internal format)
<i>ProjectName.ABS</i>	Binary file map lines in the field coordinates (an internal data format)
<i>ProjectName.DXF</i>	file <i>ProjectName.ABS</i> in the DXF format

Attention. The last 3 files can be of the project name, but can bear any other name to enable several plotting files from the same pair of pictures.

4. Preliminary setting-up of the system

4.1. Starting

The program can be started by calling VSD from an arbitrary catalog. However, it is advantageous to start the program from inside of the catalog intended especially for the job that has to be plotted using VSD. During starting the program, introducing the working catalog and the image names it is possible to return to the DOS operating system only by DOS Ctrl Break.

To start the operation of the program it is necessary to enter from the keyboard:

VSD or VSD e (for the anglo-lingual version) and to accept. The heading appears on the screen. It should be passed to the next screen by keying - in ESCAPE (or any key). Information on the graphic card and on the storage capacity appears on the screen.

For example: „Driver for Graphics Board: VESA/800x600/VRAN: 64 mb” means that the program uses the VESA driver which realizes on the screen an image in 600 lines with 800 pixels in each line and the memory block VRAM on the board is 64 kG. The next information: „Rapport Ram [kG], MemAvail = 315MaxAvail = 315, XMS.Mem = 10960XMSMax = 10960” means that after loading, there is 315 Kb of operational memory and 10960 Kb of

extended memory available. (Mem.- summary, Max - max. block). Information: „Temp.DiskFree (E:) = 2 082 304” means that there are 2 082 304 b free on the working disc for temporary files.

4.2. Project directory

The system asks then about a path to the project directory and suggest acceptance of the running directory if it comprises the file *.PRJ (formed by the system automatically, during earlier starting of the VSD program). If there is no *.PRJ file in the running directory then the system suggests the directory used recently by VSD. „Project name ? - > []” is asking for the job name with a proposal to accept the job plotted lastly (in the working catalog having been placed earlier). For example:

„Path to project directory? - > [D:\JJ]” means that the D:\JJ directory was used lastly. If we want to use that directory again it must be accepted [ENTER]. Otherwise a new path to the directory which we intend to use should be written on the screen and accepted.

4.3. Images

The system asks for a decision whether a stereogram will be plotted or a single image: „Pair of stereo-images ? (y/n)” Next it asks for giving a path to the directory which contains the image and its name (it suggests the image to be accepted which is related to the job being started): „Left photo, Name of photo-file ? - > [D:\Bytom\Bytom_L.TIF]”.

After writing in and accepting the path and the image name (if the image is located in the working directory we give only its name) the system displays information on the image and begins to form a file with extension ETK containing parameters of the image histogram in the case when the ETK file does not exist yet.

If the ETK file does exist, the question is asked whether the analysis shall be repeated. That question is usually to be negated.

In the case of a pair of images the same procedure is repeated for the right hand image. Further on, the program finds the file with the reduced images or creates it, and writes it in. The stage of indicating the images intended to be plotted is completed by visualization of a pair of reduced images on the screen. If it is the first visualization of those reductions then it occurs in parallel with working out the corresponding file. Thus it can be time consuming in the case of large output images.

The run of the program can be stopped with the Esc key during visualization. The key opens the corresponding decision window.

4.4. Viewing images

Displaceable green lines of 2 rectangles (selecting frame) appear against the background of the reduced images. They can be used to determine the part of every image that can be displayed in the corresponding half of the screen. The rectangles can be placed in the proper parts of the image using the mouse.

The tabulator enables the left or right rectangle to be activated in turn. The key [1] causes both rectangles to be moved at the same time. Accepting images in the chosen position [Enter] or the left key on the mouse) causes selected image fragments in natural scale to be visualized (one pixel of the image corresponds to one pixel on the screen). The left and right cursor appear against the back ground of the images on the screen. It is possible to go over to the adjacent frame by returning to the reduced images [V] or without doing it by centering the image around the cursor placed in the area of the image boundary (key [C]).

The image around the cursor can be magnified by pressing the [Z] key again and again. The image becomes magnified by 2, 3, 4, 8, 16, 32 times. [AltZ] should be pressed in order to read out the current magnification coefficient. The magnification coefficient appears in the frame (against black background) while in the white field the system suggests a two times higher magnification. It can be accepted or the requested magnification coefficient (integer 1 to 32) can be written in. The operator can also decide whether the magnified image will be smoothed (filtered) or whether the particular pixels of the original image magnified suitably will appear on the screen. Both in the 1:1 image as well as in the enlargement it is possible to display the adjacent image on the screen (the field of view shifted by 50%) by centering the image around the cursor placed at any point of the frame.

Counters in the upper left corner of every visualised frame determine the coordinates of a pixel in the digital image (number of the pixel in the line, and line number counted from the upper left corner of the image). On the enlargement the coordinates are given with the one screen-pixel accuracy.

4.5. Image orientation

4.5.1. Inner orientation

The purpose of the operation called inner orientation is to determine the geometrical relation between the digital image and its original (photograph) of fiducial frame. Parameters of the affine, bilinear and conformal (Helmert) transformations can be determined by measuring the image frame or the fiducial marks in the digital image and by comparing the measuring results with the master which corresponds to the original photogrammetric image. Deviations of the Helmert transformation on the fiducial marks (or on the other frame points, or reseau points) inform on the regularity of deformation of the digital image. The affine or bilinear transformations should be used as the working transformations in the program.

For the typical photogrammetric images with four or more fiducial marks, the measurement of data for internal orientation is conducted by determining the coordinates of those marks in the digital image. For that purpose, after pressing [V] key, selecting frames (displaceable rectangles) are placed to that end against a chosen mark in the left and right image using the mouse or [tabulator] or [1] keys.

[Tabulator] causes separate control of the measuring mark in the left and right photograph alternatively. The [1] key returns simultaneous control of both cursors.

After placing the selecting frame on the proper fragment of the fiducial frame of both images the 1:1 visualization of that fragment is called by pressing the left key of the mouse or the [Enter] key. Now the measuring cursor should be placed at the center of the measured mark

in the left and right (or only one) image and then the image should be significantly magnified using the [Z] or [AltZ] keys. The degree of magnification depends on the shape of the fiducial mark and on its definition. However it should be remembered that the read-out accuracy of coordinates in the digital image increases proportionally to the magnification.

For example, at a magnification $n = 20$ the read-outs from the counters in screen corners will be given with an accuracy of $1/20 = 0.05$ pixel of the original image. If the fiducial mark has a shape that can be taken in a frame shaped e.g. as a circle or rectangle, then the digital image can be magnified up to a size which permits the measuring mark of a selected shape to be readily superimposed on it. The shape of the measuring mark and its colour are selected by the [X] and [L] keys respectively.

However in case of e.g. X-shaped fiducial marks the best accuracy is obtained in the way described below. The measuring mark is placed at the end of the chosen arm of the fiducial mark, the [P] key or the middle button of the mouse is pressed and by doing it the vector line is being initiated. Then the cursor is moved to the other end of the arm animating the vector in such way so that the vector line would be placed in the axis of the arm being analyzed. During animation, the colour of the vector can be changed using the [B] key.

The axis of the other arm of the fiducial mark is marked on the screen in a similar way. Next the measuring mark is placed precisely at the intersection point of the both vectors. In order to measure the fiducial mark whose image is in the other half of the screen, the switching key [Tab] is used. The measuring mark is placed again at the intersection point of two vectors in the center of the fiducial mark. If the whole operation is performed with the image magnified by 10 times then a determination accuracy of the mark center of the order of 0.1 pixel can be achieved.

In case of a mistake in marking the vector it can be removed by touching it with the measuring mark and pressing [U].

Coordinates of the measuring marks placed at the center of fiducial marks are recorded by pressing the [I] key. A frame with 4 lines of text appears then in the lower right corner of the screen:

```
Fiduc.Point.Nr .....1
Crd x [mm] .....0.0000
Crd y [mm] .....0.0000
Left, Right, Both .....B
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The number of the marks measured and the nominal (master for the camera) mark coordinates, should be entered. The letters L, R or B shall be entered in the fourth line depending on that if the coordinates of the left, right or of both cursors are recorded.

Instead of manual entering of coordinates of fiducial marks it is recommendable to use the file: *NazwaZadania.pkt* (free format: Nr, X, Y) which should be earlier created and placed in the working directory. After entering the number of the fiducial mark manually in the first line of frame we return to the file: *NazwaZadania.pkt* by pressing key [Ins]. Following manual selection of one of the options: L, R, B, the whole measurement is accepted by [Enter]. Recording of the measurement is shown on the screen by a blue asterisk against the measured point (that visualization of the measured points can be activated or deactivated by the key [*]).

In case of a mistake the measurement can be repeated by writing new measuring results in place of the foregoing results. Before removing the foregoing measuring results the program asks a control question, which appears in a frame in the middle of the screen: „Change Pnt [n\y]?”. Pressing "y" causes the new results to be entered in place of the foregoing ones.

There is also an other method to remove measuring results: following pressing [I] the point number with negative sign is entered into the frame and the frame is accepted in one of the L, R, B options. By doing this the measuring results are being canceled. Entering a number equal to zero in frame [I] causes (after accepting the frame by [Enter]), all points written using frame [I] to be canceled. Measuring results are recorded in the file: *NazwaZadania.or*. Following the measurement of the fiducial marks one can begin to calculate the transformation coefficients of the pixel system to the photograph coordinates, initiated by [F5].

The program makes sure if we really are going to calculate the transformation, by asking: „Determination of transformation to fiducials ? (n/y)” In case of confirmation by pressing "y", a table appears on the screen which enables the kind of the higher order transformation of destination to be selected. The following transformations are available at present: affine, bilinear or projection transformation. The conformal transformation of Helmert is always calculated too, in order to facilitate the first evaluation of results. It is worth to note that the bilinear and projection transformations with four fiducial marks always give a correct fit, with no residual errors.

The types of higher order transformations and the coefficients shown in the transformation record (protocol) are automatically entered into the VSD algorithm which assignes the photograph (fiducial) coordinates (in millimeters) to the image coordinates (in pixels). Pressing the [F10] or [Esc] keys causes the screen to return to the photographs displayed. In order to change the type of transformation the menu of transformation selection should be called again by pressing the [F5] key and the calculations should be started which will be carried out on the set (file) of measuring results stored in memory. Measuring errors noted in the transformation record (protocol) can be corrected by repeating the measurement of the selected marks with the [I] key and repeating calculation [F5] using the corrected measurements. Data contained in the last record (protocol) are used for further calculations.

4.5.2. Relative orientation

Elements of relative orientation are being calculated basing on measurements of the y-parallax on the stereogram. The measurement can be made in the monocomparator mode which is introduced by the [TAB] key activating the cursor alternatively on the left or right image.

In order to measure parallaxes, reductions of photographs shall be called to the screen and the image portion shall be selected with the selecting frame in the left and right image which will appear on the screen after acceptance [ENTER] or the left key on the mouse).

After setting the cursor, in a monocular way, on the left and right image of a selected point the image together with the cursor shall be moved ([C] key) to the screen center where the correctness of position can be easier checked in absence of the y-parallax.

The measured coordinates are recorded using the [H] key, which call a small frame in the bottom right corner of the screen enabling the number of the point to be written in. The

numbers of points intended for relative orientation should not coincide with those numbers that appear in the further part of the plot. The point number is recorded having been accepted.

All points written in using the [H] key are recorded in the file of points intended for calculating relative orientations (they can be reviewed in the file: Project Name.or .

Points written in mistakenly or measured wrongly can be removed by entering into the frame the number of the point to be removed with negative sign. All points written in using the key [H] can be removed by introducing the zero number into the frame [H].

Measurement of points can be best carried out in images enlarged ([Z] or [Alt ZZ] keys) by 2 or 3 times (significantly higher enlargements can be used in case of target points) because measuring on magnifications increases the accuracy of coordinate recording. Improved readability of the image visualized on screen can be achieved by edge enhancement which can be repeated even several times. Edge enhancement is initiated by pressing the [F] key. Precise positioning of cursor on the image is often easier when the cursor is in the form of a single-pixel point which does not pulsate. A point-shaped mark of selected colour (key [L]) can be turned on or off using the [space] key.

Points for relative orientation can also be measured using the automatic correlation subroutine (key [F9]). Successful automatic correlation should be evaluated optically before the coordinates will be written into the corresponding file.

Coordinates of the measuring mark (in pixels) can be read out from the counters in the upper left and right screen corner. The counters can be turned on respectively removed from the screen using the [S] key.

After completed measurements of points for relative orientation, the angular and linear elements can be calculated which determine the position of the right photograph with respect to the spatial fiducial system of the left photograph.

The screen which enables the calculation of elements of relative orientation to be initiated is called by pressing the [F6] key. The program displays on screen the increments in the elements of relative orientation and the w , j , k , b_y , b_z elements themselves (calculated during of the first five iterations) after the elements of interior orientation have been entered and after possible initiation of reading in the distortion parameters from the *.ADP file. The model is built in the scale of photographs and the base length is being accepted as equal to the mean parallax of points measured on the model.

The calculated elements of angular orientation are given in degrees with an accuracy of 10^{-4} degree while the components of the base are given in millimeters with an accuracy up to one tenth of a micrometer. Additional iterations calculation can be initiated from the keyboard, if need. After finished iterative calculation of interior orientation, the record appears on the screen. The record incorporates the number of points used in calculations, elements of interior orientation, the number of iterations carried out, the calculated elements of relative orientation and the base length accepted for calculations.

The transformation matrix is also given (with an accuracy of ten decimal places after point) as well as tables containing model coordinates of points basing on which the orientation has been calculated (in millimeters with an accuracy to a micrometer) and the residual y-parallaxes.

The record also gives coordinates of points (in pixels up to two decimal points after point) measured in digital images, on the basis of which the elements of orientation were measured.

Having calculated the elements of relative orientation it is possible to introduce the autogrammetric operating mode of VSD.

4.5.3. Autogrammetric operating mode of the System

Relations between photograph and ground are accomplished in VSD in real time by means of a corresponding animation of the measuring mark. DLT equations (Direct Linear Transformation) are used for that purpose. The system calculates coefficients of those equations separately for every image. They are calculated from the model points, the same ones which were used for orientation (the relative orientation or the relative and absolute one depending on the stage of the preparatory work). Owing to that, the coefficients of the DLT equations are calculated in a univocal way with high precision of adjustment carried out at the stage of determining the elements of orientation taken into account.

Coefficients of the DLT transformation can also be determined directly using the known elements of exterior orientation of photographs, however this can be realized only in the case when the transformation of Helmert or the affine one were used for interior orientation. This option was developed mainly for plotting pairs of photographs being to be oriented, whose elements of orientations were determined in the framework of aerotriangulation or terratriangulation.

Calculation of DLT coefficients is initiated by pressing the [F8] key. The program prompts two options: calculations from points or from elements of orientation. Calculation from points is more advantageous, according to that was mentioned above. Then (if one declares that the control of the measuring mark will be carried out in model coordinates) the system makes the DLT calculation record accessible which contains the calculated transformation coefficients for both photographs and information on deviations at points. The coordinates x, y measured in digital images (Pnt_img, and calculated by the system using DLT (Pnt_img') and deviations of coordinates are given successively for every point (all values are expressed in pixels). In the three subsequent lines the following are given:

- three coordinates (in the model system in millimeters or meters) of points used to calculate DLT (Pnt_ter - coordinates calculated performing the relative or exterior orientation),
- model coordinates determined by the DLT equation (Pnt_ter') and
- deviation of coordinates Err_ter.

Deviations shown in this report inform on the calculation accuracy and they cannot serve for evaluation of the precision of model orientation (that evaluation has been given in the orientation record).

The dimension of a pixel in the photograph and in the model built in the scale of approx. 1:1 is given in the last lines of the record.

After leaving the report [Esc], the screen shows again reductions of photographs in which the portion of a stereogramme can be selected (using the selecting frame) which is intended to be viewed in natural scale. The cursor is animated in the autogrammetric mode.

4.5.4. Absolute orientation of the model

Absolute orientation of the model is carried out basing on measurements of control points. The portion of the image showing the surrounding of the control point is being selected in the reductions of photographs and called to the screen in the scale of 1:1 using the [Ent] key or the left button on the mouse. The transfer from the enlarged image to reductions is effected by pressing the [V] key.

The cursor is set on the image of the control point: using the mouse or keyboard arrows as to its situation and with the outer buttons of the mouse or the [F1] and [F2] keys as to its height. Precise positioning at a point can be easier achieved by controlling the cursor from the keyboard. It is advantageous to make the measurement of control points on images enlarged by a factor matched to the type of signalization. When measuring the control points the autocorrelation subroutine can be used to place the mark accurately as to its height [F9]. During measurement on a model built as a result of relative orientation, the coordinate counter in the upper left corner of the screen (yellow figures) shows three coordinates of the measuring mark in the coordinate system of the model (in millimeters). The fourth column of the coordinate counter shows the observational y-parallax which occurs on the screen. The program causes the elevation of the right image to be corrected when the parallax exceeds the value of 4 pixels which provides the operator with a good comfort of stereoscopic observation.

The model coordinates of the measuring mark (set at the control point) are recorded by pressing the [G] key which calls the frame appearing in the right bottom corner of the screen.

The number of the point shall be written into the frame. After accepting the number, the master coordinates of the control point shall be called using the [Ins] key from the ProjectName.Pkt file created earlier. The standard coordinates can be also entered by hand from the keyboard. In both cases the recording is completed by acceptance of the last frame line. All points measured in the orientation process can be signaled in the photograph. This signalization can be visualized or turned off with the grey asterisk key. A red x denotes a control point (written in with the [G] key) while a green cross denotes a points which serve for relative orientation (written in with the [H] key). Calculation of the elements of exterior orientation is initiated with the [F7] key and the system suggests the possibility of using also the coordinates of projection centers for absolute orientation (which is important mainly for orientation of nontypical models); the coordinates of projection centers should be given in the file ProjectName.Pkt under the numbers -1 and -2).

Calculation results are shown on the screen in the record of exterior orientation. The following are given: elements of the angular orientation of the left photograph (of the model), model scale, coordinates of both projection centers and the spatial transformation matrix for the left photograph (i.e. for the model). Below it, under the number of every point used for absolute orientation, the following are given: measuring results of the x, y, z coordinates of the control point in the system of the model (Pnt_mod in millimeters), model coordinates of the control point after adjustment (Pnt_mod' in millimeters), deviations of model coordinates (Err_mod), master ground coordinates (X,Y,Z) of the point (Pnt_ter in meters), ground coordinates calculated after absolute orientation (Pnt_ter') and the deviation of ground coordinates (Err_ter).

The mean registration error calculated from deviations at points (in ground measures) as well as a table with measuring results being the basis for orientation calculation (coordinates measured in digital images in pixels) are given below it.

If the analysis of deviations shown in the orientation record indicates to the necessity of repeated measurement of some control points then this can be done after leaving the orientation record by pressing the [Esc] key. Points entered with errors can be erased from the file by entering the negative number of the point to be canceled in the table called with the [G] key. Erroneously measured points can be measured again and the results should be written-in in place of the foregoing ones using the [G] key. Calculation of absolute orientation is initiated again with the [F7].

Having finished the process of determining the exterior orientation, the DLT coefficients shall be again calculated (the [F8] key) and running the VSD system using those coefficients shall be started again, as it has been described earlier.

Now the system shall be run not in model coordinates but in ground coordinates (the prompt: "do you want to control the floating mark in the model coordinate system" shall be answered by negation so that the control in the absolute system of ground coordinates would be turned on).

The record that appears on the screen after calculating [F8] the DLT coefficients in the absolute ground system is arranged similarly as the analogous record made accessible to the operator after relative orientation. However it contains both the points used for calculating the relative orientation and those measured for calculating the absolute orientation. All those points have got their coordinates in the ground system and they serve to calculate the DLT coefficients.

Starting the system in the autogrammetric (stereoplotting) mode, operating in the ground system, is the last stage of model orientation.

4.5.5. Documentation of the process of model orientation

Records which appear successively on screen after every stage of model tuning can be printed on paper and thus they provide a documentation of all stages of model preparation.

A set of the final versions of the individual records is moreover automatically recorded in the working catalog in the ASCII files: _OR_INT.WYN, _OR_REL.WYN, _OR_ABS.WYN, _OR_DLT.WYN.

Those files are accessible only till to the moment of a repeated execution of an operation completed with a record, making reference to the same working directory even in case of using a different job name.

Moreover, the system creates for every job a binary file ProjectName.LU and an ASCII file, corresponding to it, named ProjectName.or which contains lists of coordinates of the following groups of points:

- numbers and coordinates of fiducial marks:
data from camera calibration [mm] and the ones measured in the digital image [in pixels] for the left and right photograph,

- numbers and coordinates of points used for the relative orientation in the pixel system (in photographs) and in the ground system,
- numbers and coordinates of the control points used:
in the pixel system (in photographs) and in the ground system,
- numbers and coordinates of the remaining ground points measured in the stereogramme and recorded using the [J] key in the pixel system (in photographs) and in the ground system.

5. Stereoscopic measurement of elements of vectorial map

Control of the spatial measuring mark in the autogrammetric (stereoplotting) mode in the ground coordinate system provides possibility to measure terrain details and record them as vectorial topical layers.

The VSD system enables the vector lines to be distinguished in 7 contrasting colours (selected with the [B] key) against the background of half-tone, black-and-white or colour digital images.

The measurement is made using the spatial cursor whose shape can be selected with the [X] key as a circle, square, arrow or cross. The measuring element is a pulsating dot at the center of the cursor (at the top of the arrow-head). The dot itself can be used for precise aiming (turned on/off with the [Space] key) with identical colour as the cursor. The dimension of the dot is equal to one screen pixel. The cursor can be of one the 8 contrasting colours selected with the [L] key.

The cursor can be moved over the screen using the mouse (as to x,y situation) and with the outer buttons of the 3-key mouse (as to the height or depth of the model). The cursor can be also controlled from the keyboard. Four arrows serve to animate the cursor situationally while the [F1] and [F2] keys vary the cursor's depth against the background of the model.

The amount of the cursor's step on screen can be adjusted with the grey key [+] and [-]. Setting the cursor accurately at a selected detail can be best achieved by controlling it from the keyboard having set the minimum cursor step (i.e. pixel by pixel). The [F1] and [F2] keys move the cursor precisely along a vertical line (the x,y axis). The mouse buttons also vary the cursor depth but not always along a vertical line because they diminish or increase the x-parallax components of the cursor symmetrically in both photographs. They move one time the left cursor another time the right cursor alternatively by the same value but in opposite directions. Quick changes in the parallax (i.e.in the height) of the cursor according to an identical algorithm can be achieved by switching the situational motion of the mouse to the parallax motion (and back) using the [A] key.

Selection of the image area intended for vectorization is effected with the selecting frame (the green small frames) in reductions of photographs. The [V] key is used in order to pass from the basic or enlarged images to reductions. By accepting the selecting frames at the selected position [Enter] one passes to the frame in the basic scale (image pixel = screen pixel) and then to the enlargement using the [Z] key which enlarges stepwise by 2,3,4,8,16 and 32 times or the [AltZ] key which enlarges by a factor entered from the keyboard. A stepwise reduction in the enlargement is achieved using the [M] key. From the level of an enlarged

image we can come back for a time to an image in the basic scale using the [O] key. However the [O] key makes only the monitoring possible, while no vectorization can be made in the image in basic scale called in that way. Passing from an enlarged frame to a frame in the basic scale can be done also using the [R] key. Image vectorization can be made in a basic frame obtained in that way.

An image in the basic scale can be also called without using the selecting frames and the reduced images if we know the coordinates of an arbitrary point in the image part being of interest. The window in the bottom right corner of the screen, where the coordinates can be written-in, is called with the [zero] key. Accepting the window causes the basic frame to be called whose center has the required coordinates.

"Plotting a map" begins by setting the cursor in a stereoscopic manner at the chosen detail. The initial point of the vector is recorded using the [P] key or the middle button on the mouse. Moving the cursor animates now a straight line attached at the recorded point. The colour of that line is selected with the [B] key. However it is necessary to be careful because the system enables a different colour [B] to be selected for every side of an open polygon and it is not possible to change the colour of the line once it was drawn (you can erase the line though). The colour, to which an alphanumeric code can be ascribed, divides the details being recorded into thematic layers. After setting the cursor at a subsequent point, its position is again recorded using the mouse or the [P] key if the open polygon is to be continued or if the last point of the polygon is recorded with the [K] key.

If the polygon has to be closed at the initial point, then it is enough to set the cursor near it. Precise closing the open polygon is brought about automatically using the [D] key.

It is also possible to plot a line being orthogonal to the existing one. After setting the cursor at the point that has to be orthogonally projected onto the existing line, the vector is initiated with the [P] key. Moving the cursor towards the existing line animates the vector which follows the cursor. Using the [N] key, sets the vector orthogonally to the existing line and the intersection point of both lines is automatically recorded. The [N] key causes orthogonal spatial projection while the [AltN] key causes the same operation to be effected but in the horizontal projection plane.

The system also enables the vector map to be corrected. In order to remove the unnecessary fragments of an open polygon displayed on screen, the selected vectors can be touched with the cursor and canceled with the [U] key. A part of the trajectory between the place indicated by the cursor and the end of the trajectory can be canceled by the [TU] keys. Not all model lines consist of sufficiently long sections so as they could be approximated by a polygon.

Curved lines on the model that are difficult to be approximated by a polygon can be recorded using a subroutine which is started with the [T] key. It causes the cursor trajectory to be recorded pixel by pixel, which gives an impression that the details of the model are being enclosed by a continuous curved line.

The colour of the trajectory can be selected using the [B] key up to the moment of recording the end of the section (the [K]). Recording a trajectory is more memory - consuming than recording a polygon.

Interpretation of a model and recording a vectorial map must often be made on the measured frame enlarged by 2-3 times which sometimes causes the need to move to the next screen frame in order to record the end of the vector. For that purpose the cursor shall be set near the

frame edge, approximately in the expected direction of the vector and the [C] key shall be pressed. The image on screen is then shifted so that the fragment on which the cursor is set becomes placed at screen center. Such a transcending [C] causes the image to be moved by half a frame.

The measuring system functions in such a manner that cursors (spatial measuring marks) are moved against the background of stationary images. As the relative orientation of the stereogramme plotted usually deviates from a normal case, the y- parallax of images is variable, which could make the observations difficult. In order to minimize that inconvenience a mechanism was introduced into the system that supervises the visual y-parallax. That mechanism (subroutine) corrects the situation of the right image when the visual parallax exceeds the amount of 4 screen pixels. If however in an exceptional case (during precise positioning) this residual parallax disturbs the operator then it can be reduced in each case down to zero using the [C] key. At the same time the observation area is moved to the center of the left and right frame on the screen.

The autocorrelation subroutine can be used for precise setting the cursor at the ground surface. After approximate selection of the image areas corresponding to each other using the left and right cursor (in monocularly or stereoscopic way), the autocorrelation procedure shall be started with the [F9] key. It is necessary to verify visually the success of the automatic procedure. In the present program version the autocorrelation function [F9] operates correctly only for monochromatic images.

In the framework of the single file of thematical layers the 7 topical layers can be vectorized which are distinguished by colours selected with the [B] key. If greater numbers of topical layers have to be read out from the stereogramme then they must be done by portions and recorded in separate files.

The results of vectorization can be seen on the screen in the form of coloured lines against the background of the half-tone image of the ground. In order to record vectorial map on disc it is necessary to initiate the return to DOS procedure using the [Q] key. After acceptance of a corresponding control question, a part of the vectorial map appears on the screen without the half-tone background in a procession onto the plane of the left and right photograph. This is stereoscopic image of the vectorial map. That image of the vectorial map has to be accepted and the file names have to be given into which the vectorization results will be written-in. Lines of the vectorial map in the image coordinate system (in the left and right image) will be written - in into the ASCII file named *MAP (in internal format). Vectorization results in the absolute (ground) reference system will be written-in into the binary file named *.ABS (in internal format). The contend of the *.ABS file in the DXF format will be written - in into the ASCII file named *.DXF. Thus recording the *.ABS file earlier is a precondition of recording the *.DXF file. Using a file name already existing in the working catalog for one of the new files causes the former file to be canceled. The VSD system issues a warning. After having recorded the vectorial map the system passes to DOS.

If it is intended to vectorize a next file of topical layers from the same stereogramme, it is necessary to call the VSD system from the same working directory. The oriented model, ready to be vectorized, will appear on screen.

6. Cooperation of VSD with the Land Information System

The Video Stereo Digitizer produces a file of the vector map in the DXF format which can be incorporated into the system of topical layers LIS or GIS after assigning the corresponding codes to the topical layers distinguished by colours during vectorization.

Selected 3D layers of the vector map LIS can be visualized against the background of half-tone images, using the VSD system. To that end it is necessary to use the DXF_ABS.EXE transformation program (provided with the composition of the VSD package) which allows the DXF file to be transformed into the internal ABS format being proper for VSD. That program allows layers to be selected and visualization colours to be modified.

The file prepared using the transformation program, similarly as own VSD files with colours modified by the transformation program, can be visualized against half-tone images in the VSD system. The ABS file is introduced on screen (where there are already stereoscopic half-tone images) calling with the [E] key a window (in the right bottom corner of the screen) where the name of the ABS file should be written-in.

Several files of the vector screen can be one by one written-in to the screen by writing them successively onto each other. A vector map compiled in that way can be stereoscopically analyzed against the half-tone images. Modifications can be entered consisting in removing or adding lines in chosen colours. The joined layers together with possible corrections are written-in and recorded as a single file (in the way given in the foregoing chapter) under arbitrarily chosen name in the MAP and/or ABS format as well as optionally in the DXF format.

From the description given above it results that there is full possibility to use VSD as a smart SIT terminal for the needs of verification and updating of the vectorial topical layers.

The half-tone images are taken from the digital image library. If the original image is a photograph picture (aerial or satellitary) then it should be scanned applying suitable resolution (not lower than 600 dpi) and corresponding geometrical precision which would ensure metricity of the model.

Half-tone images can be stored in the library on magnetic tapes or even better on exchangeable magnetic discs or optical-magnetic discs with a capacity of not less than 0.25 giga byte. As a single aerial photograph with a resolution of 600 dpi (black-and-white or colour) requires 30 MB thus 8 photographs can be recorded on one 0.25 GB disc. This provides the SIT users with the possibility to use digital half-tone images freely.

Vizualization of 2-dimensional vector maps (2D) from LIS files against a digital stereogram is possible only in the case when the third coordinate can be interpolated from the numerical terrain model (LIS of the 2D + 1D type). If there is no numerical model of terrain topography in the LIS files then it can be plotted by measuring suitably dislocated height-points on the digital stereogram using VSD. In both cases the interpolation of the third coordinate for all points of the vector map being visualized shall be carried out in the framework of preparatory work using a suitable program, e.g. the SCOP program (developed by the Technical University of Vienna and the INPHO Company in Stuttgart), the SURFER program or another one.

A numerical model of the terrain can be also plotted using one of the programs for automatic picture correlation, e.g. the Leica INTERGRAPH program or the program developed at the Agricultural - Technical Academy in Olsztyn [Jędrzycka 1995].

A digital orthophotograph can be also used for visualization of 2-dimensioned vector maps (2D) from files included into the LIS data base, against a half-tone image. In such a case the VSD system visualizes a half-tone image on the whole screen. Such type of VSD operation is initialized just after starting VSD by negating the system question: „Pair or stereoisimages ?” Further operations, i.e. adapting coordinate system (measuring the controlpoints) are executed by the [I] key. Calculation of the coefficients of absolute transformation and controlling the cursor in the absolute system of coordinates are initiated with the [F5] key. Vectorization is carried out using the functions described earlier which are built-in into the VSD system.

However it should be noted that making an orthophotograph is more time-consuming than interpolating the height coordinates for points of a plane (2D) vector map on a numerical model (considerable lower number of interpolated points and differential processing, e.g. a digital image is not necessary). The more that the advantage of using a virtual orthophotograph is rather insignificant. It can be boiled down only to a more easy operation of the orthophotomap files organized, e.g., in sections similarly as printed maps (hardcopies). Visualization of a 2D vector map against non-stereoscopic, single half-tone images is possible, using VSD and application of the intermediate stage of producing a digital orthophotograph is not necessary. However, at the present development stage the VSD system is not yet adapted to cursor animation using the numerical model of terrain surface, i.e. to the so called monoplotting. Introducing that function into VSD in future will enable a vector map to be edited using single perspective images not being processed to the form of an orthophotography. Despite the fact that the readability of half-tone images becomes significantly improved when use of stereoscopy is made, many plots can be successfully made on plane images. If it is not intended to use hardcopies of a half-tone map with a line drawn on it, then using that form of a map on screen is more economic with applications of the monoplotting concept than with applications of the orthophotograph concept.

The usefulness of VSD for vectorization of scanned aerial stereoscopic digital images and for updating the LIS vector maps was verified on photogrammetric pictures of a part of the area of the Cracow town (Nowa Huta) taken with the RC20 camera of Wild and on photographs of parts of the Gdansk town taken with the Hasselblad (60 x 60 mm) camera.

A pair of colour photographs (1 : 5000, $c_k = 152\text{mm}$) of the Nowa Huta terrain was reduced to a digital form using the Howtek scanner. Scanning resolution of 1000 dpi was used. It was plotted, using VSD, on photographs with resolution reduced to 500 dpi which corresponds in the field to a pixel of 0.24m. 513 corners of buildings were measured and the coordinates were compared with their counterparts taken from the data bank of the Małopolska System of Terrain Information. The comparison showed a mean point situation error of $m_x = 0.61\text{ m}$, $m_y = 0.68\text{ m}$. The mean error was again calculated after rejecting deviations exceeding by a factor of 3 the mean error calculated from the first comparison. Five points were rejected. This time a mean error of $m_x = 0.56\text{ m}$ (2.3 pixel) and $m_y = 0.65\text{ m}$ (2.7 pixel) was obtained with maximum deviations of $dx_{\max} = 1.65\text{ m}$ and $dy_{\max} = 1.90\text{ m}$. The arithmetical mean calculated from the deviations, testifying to a displacement of the origin of the coordinate system, was $S_x = -0.08\text{ m}$ (0.3 pixel) and $S_y = +0.22\text{ m}$ (0.9 pixel). Taking into consideration the fact that the vector map to which the VSD measurements were compared was created by digitalization of a graphical map section (1: 500) it can be accepted that the divergences of measurements are also burdened

by the errors of the numerical LIS map whose mean error is estimated to be ab. 0.5mm which corresponds to 0.25 m in the field.

Better estimation of vectorization precision of a stereogram using VSD give the results of comparison between analytic plotting stereograms of original monochrome photographs with the plots of digital stereograms. A stereogram of black and white photographs of a terrain in Nowa Huta (RC 20 of Wild, $c_k = 152$ mm, 1:5 300) was scanned using a scanner of middle class with a resolution of 600 dpi (pixel $F = 43$ mm which corresponds to $F = 0.23$ m in the field). 116 points were measured on VSD, whose coordinates were compared with coordinates obtained in analytic way from measurement of original photographs on the Stecometer. The following situation precision was obtained from raw results: $m_x = m_y = 0.30$ m which corresponds to 1.3 pixel. After taking into consideration the displacement of the systems $S_x = 0.03$ m, $S_y = -0.02$ m a mean error of image registration of $m_x=0.24$ m (1.0 pixel), $m_y = 0.22$ m (1.0 pixel) was obtained as a results of comparison of results using the Helmert transformation.

A similar analysis consisting in comparing measurement results on VSD with data on 139 points taken from the LIS, gave the following results. Comparison of files by simple subtraction showed errors $m_x = 0.60$ m (2.6 pixel), $m_y=0.41$ m (1.8 pixel), $S_x = -0.27$ m (1.2 pixel), $S_y = -0.03$ m (0 pixel). A comparison using the Helmert transformation showed deviations $m_x = 0.53$ m (2.3 pixel), $m_y = 0.41$ m (1.8 pixel).

In the both analyses mentioned above, building corners were selected for comparison. The hoods were not taken into consideration. Thus the characterization of measurement consistency of DVP with the LIS data is burdened with the fact that the points compared were not identical.

On the stereogramm of aerial photographs of the Gdynia town taken with a Hasselblad camera (60 x 60 mm, $c_k = 80$ mm, scale 1:11700) scanned with a resolution of 600 dpi, 104 building corners were measured and their coordinates were compared with data taken from the LIS data base. Comparison of results yielded mean errors $m_x = 0.56$ m = 1.1 pixel, $m_y = 0.44$ m = 0.9 pixel which is to be considered as a very good results. Because of the flatness of the terrain the content of topical layers of the LIS vector map could be analyzed against the background of the half - tone image on VSD screen after overlaying the both images without any special preparation.

In order to overlay the image of a LIS vector map onto black-and-white half-tone digital images, 30 height-points were measured which were dislocated at terrain surface and which formed a dispersed height model. Using the SURFER program a height interpolation was made which permitted the 2D map to be transformed from the Autocad into a 3- dimensional map suitable for visualization against the stereogram. A very good superposition of vector line images onto the images of visible parts of building basements. A successful trial of spatial visualization of the LANDSAT image of Cracow area was also carried out. It consisted in creating a stereo-partner of the satellite image using a program for differential processing of digital images developed by our team in the mid - 80 s. The satellite image together with the stereo-partner provided a very good stereoscopic model which significantly improved the image readability and suitable for measurements using VSD.

Experimental work confirmed the suitability of the VSD system for the users of the Systems of Terrain Information both for better interpretation of vector map contents and for updating the contents of some topical LIS layers.

7. Conclusion

The Video Stereo Digitizer (VSD) system is an analytic digital stereoplotter, i.e. a stereoscopic photogrammetric working station installed on the PC basis. Owing to adaptation of the VSD system to the PC computers the system is suitable for mass-use as a smart LIS terminal as well as for self-depending use for vectorization of stereograms and orthophotomaps.

The system of stereoscopic observation is not complicated. It is based on the use of a mirror stereoscope and ensures good observation comfort at low cost. Experimental plotting of black-and-white and colour aerial photographs of urban terrains allowed the possibility of using VSD for visualization of vectorial half-tone images and the possibility of making supplements to and corrections of vector maps recorded in LIS topical layers with the aid of VSD to be evaluated. The evaluations confirmed full suitability of VSD for cooperation with the LIS system. Cumulative visualization of stereoscopic or single half-tone images together with selectively chosen topical layers of a vector map creates an easy way of interpreting LIS resources in confrontation with the terrain image for users of the systems of terrain information.

The Video Stereo Digitizer was presented at a number of domestic and foreign symposia and it was also described in many publications. Because of its technical and economic advantages it was implemented in laboratories of domestic (Cracow, Warsaw, Szczecin) and Foreign (Vienna, Torino, Zagreb) universities where it was well appreciated.

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JÓZEF JACHIMSKI

VIDEO STEREO DIGITIZER - MAŁA CYFROWA STEREOFOTOGRAMETRYCZNA STACJA ROBOCZA DLA POTRZEB SIT I INNYCH ZASTOSOWAŃ

STRESZCZENIE

Komputerowe Systemy Informacji o Terenie (SIT) pozwalają na gromadzenie, przetwarzanie i udostępnianie informacji dotyczącej sposobu użytkowania ziemi i budowli, warunków prawno - własnościowych a także geometrycznych, technicznych i innych cech terenu, budowli i urządzeń znajdujących się na określonym obszarze.

Informacje geometryczne gromadzone są w SIT w postaci tematycznych map numerycznych, które z natury rzeczy prezentują tylko wybiórcze dane o terenie i obiektach. Mapy wąskotematyczne znacznie mogą zyskać na czytelności jeśli będą interpretowane na tle fotograficznego obrazu terenu lub obiektu. Zdjęcie (lub ortofotogram) pokazane w tle mapy wektorowej, jeśli jest aktualne, może być wykorzystane również do uzupełnienia treści niektórych map wektorowych, a zwłaszcza do odczytania tych informacji o sposobie zagospodarowania terenu, które nie są objęte treścią map tematycznych. Szczególnie dobrze nadają się do tego celu stereogramy lub stereoortofotogramy.

Celem badań objętych grantem było opracowanie systemu ekranowej łącznej prezentacji map wektorowych i obrazów półtonalnych (fotogramy, ortofotogramy, stereogramy, stereoortofotogramy), zintegrowanego z systemem pomiarów dopełniających prowadzonych na półtonalnych obrazach cyfrowych (Video Stereo Digitizer). System ten ma stanowić końcówkę SIT.

Opracowano system Video Stereo Digitizera (VSD), który jest analitycznym cyfrowym autografem, czyli stereoskopową fotogrametryczną stacją roboczą zainstalowaną na platformie PC. Dzięki przystosowaniu systemu VSD do komputerów typu PC, system ten nadaje się do masowego stosowania jako inteligentna końcówka SIT, a także do samodzielnego wykorzystania przy wektoryzacji stereogramów i ortofotomap.

Nieskomplikowany system obserwacji stereoskopowej, oparty o stereoskop zwierciadlany, zapewnia dobry komfort obserwacji przy niskiej cenie [16].

Video Stereo Digitizer zbudowano przy podstawowym założeniu, że na ekranie monitora PC-SVGA, podzielonym pionową linią na dwie połówki, wizualizowane są dwa obrazy cyfrowe stanowiące stereogram [14]. Obrazy te obserwować można przez stereoskop zwierciadlany ustawiony przed ekranem. Na tle każdego z obrazów animowany jest kursor. Do animacji kursora służy "mysz". Kursory mogą być poruszane na zmianę na tle lewego lub prawego obrazu, a ich położenie może być rejestrowane. System wyposażony jest również (podobnie jak autografy analityczne) w tzw. program czasu rzeczywistego, który umożliwia wyliczanie z częstotliwością 50 Hz współrzędnych tłowych dla podanych terenowych współrzędnych punktów przy znanych elementach orientacji zdjęć. Współrzędne terenowe generowane są z wykorzystaniem ruchu myszy ($\pm X$, $\pm Y$) oraz przycisków myszy ($\pm Z$), lub z wykorzystaniem

klawiatury. Dla zapewnienia komfortowej obserwacji stereoskopowej, w czasie pracy przyrządu redukowana jest paralaksa obserwacyjna przez automatyczne przemieszczanie w pionie prawego obrazu.

System wyposażono w funkcję umożliwiającą powiększanie obrazu na ekranie (do 32 razy) i "rysowanie" (wektoryzację) treści stereogramu na dowolnym powiększeniu. Wprowadzono dwa podprogramy działające na obrazie cyfrowym, podprogram filtrowania powodujący poprawienie czytelności krawędzi na obrazie, oraz podprogram autokorelacji, powodujący automatyczne odszukanie na prawym obrazie tego szczegółu, który wskazany jest kursorem na lewym obrazie (autokorelacja działa obecnie tylko na obrazach czarno-białych). System VSD umożliwia rejestrację mapy wektorowej "narysowanej" na ekranie, przy czym równocześnie rejestruje się do 7 warstw tematycznych wyróżnionych różnymi kolorami na tle obrazu półtonalnego. Na obrazy półtonalne można też na ekranie nałożyć mapę numeryczną pobraną z bazy danych SIT, pod warunkiem jednak, że każdy punkt mapy numerycznej ma przypisane trzy współrzędne (X,Y,Z). W przypadku dwuwymiarowej bazy danych (2D) można trzecią współrzędną wyinterpolować z modelu numerycznego pomierzonego z wykorzystaniem VSD. Interpolacja musi się jednak odbyć poza systemem (np. programem SURFER lub SCOP). System umożliwia też wizualizację mapy 2D na tle ortofotografii. Na tle ortofotografii można, podobnie jak na tle stereogramu, prowadzić wektoryzację treści obrazów półtonalnych i wprowadzać korekty do istniejącej mapy numerycznej.[17,18,49-51].

W typowym przypadku, gdy nie są znane elementy orientacji zdjęć, należy przeprowadzić strojenie etapowe. W pierwszym etapie (orientacja wewnętrzna) wyznacza się parametry transformacji obrazu cyfrowego do układu zdjęcia. W drugim etapie określa się elementy orientacji wzajemnej (przez pomiar paralaks poprzecznych na punktach Grubera). W trzecim etapie określa się elementy orientacji bezwzględnej w oparciu o punkty dostosowania. Sterowanie kursorem w trybie autogrametrycznym osiąga się przez wyznaczenie współczynników DLT na podstawie współrzędnych punktów pomierzonych dla potrzeb orientacji wzajemnej oraz na podstawie współrzędnych punktów dostosowania. Współczynniki DLT dla zdjęć niemetrycznych można w systemie VSD wyznaczyć z co najmniej 6 punktów dostosowania z pominięciem drugiego i trzeciego etapu strojenia modelu.

W ramach grantu wykonano również krótką serię zdjęć lotniczych terenu Krakowa (1 : 5000), które wraz z innymi materiałami fotogrametrycznymi stanowią podstawę przeprowadzonych prac testowych i analiz dokładnościowych.

Parę zdjęć kolorowych 1 : 5 000, $c_k = 152$ mm, terenu Nowej Huty sprowadzono do postaci cyfrowej z wykorzystaniem skanera Howtek. Skanowano z rozdzielczością 1000 dpi, a opracowanie wykonano z wykorzystaniem VSD na zdjęciach o rozdzielczości zredukowanej do 500 dpi, co odpowiada w terenie pikselowi o wymiarach 0.24 m. Pomierzono 513 narożników budynków i porównano współrzędne z ich odpowiednikami zaczerpniętymi z banku danych Małopolskiego Systemu Informacji Terenowej. Uzyskano z porównania błąd średni położenia punktu $m_x = \pm 0.61$ m, $m_y = \pm 0.68$ m.

Biorąc pod uwagę fakt, że mapa numeryczna, do której przyrównywano pomiary VSD, powstała przez digitalizację sekcji mapy graficznej w skali 1 : 500, można przyjąć, że niezgodności pomiarów są obciążone też błędami mapy numerycznej SIT, której błąd średni oceniany jest na około 0.5 mm, co odpowiada 0.25 m w terenie.[20].

Lepsza ocena dokładności wektoryzacji stereogramu z wykorzystaniem VSD jest wynikiem porównania analitycznego opracowania stereogramu monochromatycznych zdjęć oryginalnych z opracowaniem stereogramu cyfrowego. Stereogram czarno-białych zdjęć terenu Nowej Huty (RC 20 Wilda, $c_k = 152$ mm, 1 : 5 300) zeskanowano średniej klasy skanerem UMAX z rozdzielczością 600 dpi (piksel = 43 um co odpowiada = 0.23 m w terenie). Na VSD pomierzono 116 punktów, których współrzędne porównano ze współrzędnymi uzyskanymi metodą analityczną z pomiaru zdjęć oryginalnych na Stecometrze. Z surowych wyników uzyskano dokładności sytuacyjne $m_x = m_y = 0.30$ m co odpowiada 1.3 piksela. Po uwzględnieniu przesunięcia układów $S_x = 0.03$, $S_y = -0.02$ m uzyskano przy porównaniu wyników z wykorzystaniem transformacji Helmerta błąd średni wpasowania $m_x = 0.24$ m (1.0 piksela), $m_y = 0.22$ m (1.0 piksela). Podobna analiza polegająca na porównaniu wyników pomiaru na VSD z danymi dotyczącymi 139 punktów zaczerpniętymi z Małopolskiego SIT dała następujące wyniki. Porównanie zbiorów przez proste odjęcie wykazało błędy $m_x = 0.60$ m (2.6 piksela), $m_y = 0.41$ m (1.8 piksela). Porównanie z wykorzystaniem transformacji Helmerta wykazało odchyłki $m_x = 0.53$ m (2.3 piksela) i $m_y = 0.41$ m (1.8 piksela) [20].

W obu powyższych analizach do porównania wybrano narożniki domów, przy czym nie uwzględniano szerokości okapów. Tak więc charakterystyka zgodności pomiarów DVP z danymi z SIT obciążona jest przez nieidentyczność porównywanych punktów.

Celem nałożenia obrazu mapy wektorowej SIT na czarno białe półtonalne obrazy cyfrowe pomierzono 30 punktów wysokościowych rozmieszczonych na powierzchni terenu tworzących rozproszony model wysokościowy. Z wykorzystaniem programu SURFER wykonano interpolację wysokości, co umożliwiło przetransformowanie mapy 2D z Autocada do postaci mapy trójwymiarowej, nadającej się do wizualizacji na tle stereogramu. Uzyskano bardzo dobre nałożenie się obrazów linii wektorowych na obrazy widocznych fragmentów przyziemi budynków.

Na stereogramie zdjęć lotniczych miasta Gdyni wykonanych aparatem fotograficznym Hasselblad (60 x 60 mm, $c_k = 80$ mm, skala 1 : 11 700) zeskanowanych z rozdzielczością 600 dpi pomierzono 104 narożniki domów i porównano ich współrzędne z danymi zaczerpniętymi z bazy danych SIT. Z porównania wyników uzyskano błędy średnie $m_x = 0.56$ m = 1.1 piksela, $m_y = 0.44$ m = 0.9 piksela, co należy uznać za wynik bardzo dobry. Z uwagi na płaskość terenu

treść warstw tematycznych mapy wektorowej SIT można było analizować na tle obrazu półtonalnego na ekranie VSD po nałożeniu obu obrazów na siebie bez specjalnych przygotowań.

Przeprowadzono również pomyślną próbę przestrzennej wizualizacji obrazu LANDSAT obszaru Krakowa. Polegała ona na wytworzeniu stereopartniera obrazu satelitarnego z wykorzystaniem opracowanego przez nasz Zespół w połowie lat 80-tych programu do różniczkowego przetwarzania obrazów cyfrowych. Zdjęcie satelitarne wraz ze stereopartnerem dało bardzo dobry model stereoskopowy, podnoszący znacznie czytelność obrazu i nadający się do pomiaru z wykorzystaniem VSD.

Prace doświadczalne potwierdziły przydatność systemu VSD dla użytkowników Systemów Informacji Terenowej, zarówno dla lepszej interpretacji treści map wektorowych jak też dla aktualizacji treści niektórych warstw tematycznych SIT

Dokładność opracowań z wykorzystaniem VSD zależy w dużej mierze od dokładności odtworzenia geometrii obrazu srebrnego przez skaner, który zamienia obraz srebrowy na postać cyfrową. Ponieważ do pozyskania obrazów cyfrowych wykorzystuje się często skanery poligraficzne o nieznanach parametrach wierności geometrycznej, stąd należało zbadać jakość geometryczną obrazów cyfrowych uzyskanych przy ich użyciu. Przebadano skaner UMAX 1200 SE wykorzystywany w Zakładzie Fotogrametrii i Informatyki Teledetekcyjnej do pozyskiwania obrazów cyfrowych dla VSD. Niekorygowane obrazy cyfrowe pozyskane przy użyciu tego skanera wykazały odchyłki dochodzące do kilkunastu pikseli pomiędzy punktami wzorca i jego obrazem cyfrowym. Błąd średni wpasowania (transformacja Helmerta) wyniósł dla formatu 15 x 22 mm około 4-5 pikseli. Ponieważ stwierdzone błędy są bardzo duże, dlatego zaproponowano dwie metody ich korygowania [4,5]. W wyniku stosowania tych metod można poprawić dokładność odtworzenia geometrii obrazu do poziomu charakteryzującego się błędem $m_x = m_y = \pm 0,3$ piksela przy maksymalnych odchyłkach nie przekraczających 1 piksela.

Podsumowując należy stwierdzić, że system Video Stereo Digitizera (VSD) jest analitycznym cyfrowym autografem, czyli stereoskopową fotogrametryczną stacją roboczą, zainstalowaną na platformie PC. Dzięki przystosowaniu systemu VSD do komputerów typu PC, system ten nadaje się do masowego stosowania jako inteligentna końcówka SIT, a także do samodzielnego wykorzystania przy wektoryzacji stereogramów i ortofotomap.

Nieskomplikowany system obserwacji stereoskopowej, oparty o stereoskop zwierciadlany, zapewnia dobry komfort obserwacji przy niskiej cenie. Opracowania doświadczalne czarno-białych i kolorowych zdjęć lotniczych terenów zurbanizowanych pozwoliły ocenić możliwość wykorzystania VSD do wizualizacji obrazów wektorowo-półtonalnych, a także ocenić możliwość wykonywania z użyciem VSD uzupełnień i korekt map wektorowych zapisanych w warstwach tematycznych SIT. Oceny te potwierdziły pełną przydatność VSD do współpracy z systemem SIT. Łączna wizualizacja stereoskopowych lub pojedynczych obrazów półtonalnych wraz z selektywnie dobraćanymi warstwami tematycznymi mapy wektorowej stwarza użytkownikom systemów informacji terenowej łatwość interpretacji zasobów SIT w konfrontacji z obrazem terenu.

Video Stereo Digitizer był prezentowany na szeregu sympozjach krajowych i zagranicznych a także opisany w kilku publikacjach. Z uwagi na walory techniczne i ekonomiczne został wdrożony w laboratoriach uczelni krajowych (Kraków, Warszawa, Szczecin) i zagranicznych (Wiedeń, Turyn, Zgrzeb), gdzie spotkał się z dobrymi ocenami.