Application of the on-line strip triangulation program STRAUS

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1.   General

For highly accurate photogrammetric single point determination, analytic phototriangulation is generally adopted on a worldwide scale. Highest accuracy is obtained by using the bundle method in connection with analytic plotting instruments or precision comparators (stereo or mono). For provision of control coordinates for photogrammetric stereoplotting the method of independent models is used, too. With this, coordinates can be determined by analog stereo plotters. Use of computer-aided techniques at photogrammentric plotting instruments caused the development of the on-line triangulation method with computer-aided stereo-plotting systems. On-line triangulation is a method of measurement and immediate processing of measured values which allows the operator to recognize and eliminate coarse errors and other model mistakes during measuring.

2.   Concise description of the program package

2.1.   DZT 90 x 120/RGS instrument configuration

The DZT 90 x 120/RGS computer-aided stereoplotting system of the Kombinat VEB Carl Zeiss JENA can be affiliated to the analog stereoplotting systems (Stereometrograph, Topocart, Stereoplot) as a complementary unit.

Integration of such a system into the processing for graphic mapping alters the restitution technologies. During restitution, the stereo operator has an additional display with keyboard, a double pedal switch and a functional keyboard for control of the automatic drawing. For determination of control marks for graphic, numeric, and photographic interpretation of photographs the on-line strip triangulation program STRAUS is used for the DZT 90 x 120/RGS computer-aided stereo plotting system. This program uses the possibility of the system-internal graphic output.

2.2. Program structure

The STRAUS strip triangulation program is for measurement,
calculation, and adjustment of aerial triangulation strips.
The program is based on the technique of independent models.
Primary data (model coordinates) are acquired in relatively
oriented photogrammetric models with the DZT 90 x 120/RGS
during measurement of a triangulation strip at the stereoplotter.
Strip formation is performed after measurement and check of
a scale model as well as orientation of the first strip model.
Within one strip number of models is not limited. During measuring
up to 25 reference points (projection centres, tie points,
control points) can be registered within one model. For one
triangulation strip up to 40 control points (planimetric,
height, and complete control points) can be considered.

Program package STRAUS consists of four part programs. All
programs are interlinked via common data files. The part
programs are MACHINE, CENTRE, STRIP, and GRID.

2.2.1. MACHINE program

This program specifies the kind of the plotting machine used
in strip triangulation, the formats for coordinate recording,
the admissible errors in double measurements, and parameters
for the connection of measuring instruments. After call-up
of the program and after every parameter change (possible
by simple exchange operation), the current assignments are
listed on the display. Before the processing of an aerial

triangulation strip the coordinates of the control points
have to be stored as a file on the floppy disk.

2.2.2. CENTRE program

In aerial triangulation the projection centres are included
in the measurement and computation process. For setting the
projection centre during the model measurement, special setting

marks are used. The coordinate differences between the real projection centres and the setting marks have to be determined by a calibration measurement. This determination of the coordinates of the projection centres is performed by spatial intersections of straight lines. The resulting correction vectors of the setting marks are stored and taken into account during on-line strip triangulation in the measurement of the projection centres of each model.

The CENTRE program can be called up several times during one strip triangulation.

2.2.3. STRIP program

The STRIP program is the measuring and processing program proper for on-line strip triangulation according to the method of independent models. It is subdivided into four subroutines:

- Strip formation
- Absolute strip orientation
- Graphical representation of error vectors
- Calculation of setting elements

2.2.3.1 Strip formation

This subroutine serves for the measureemnt and recording of the coordinates of the projection centres, of the tie points and control points in the relatively oriented photogrammetric models. This subroutine performs the strip formation from the individual photogrammetric models at the model scale and in the orientation of the first model of the triangulation strip. After the conclusion of the measurement of each model the other subroutines of STRIP may be called up.

2.2.3.2. Absolute orientation

This subroutine transforms the triangulation strip existing at the model scale and in the orientation of the first model of the strip into the ground coordinate system (control points). After the rigorous spatial Helmert transformation the residual errors at the control points in the ground coordinate system

are indicated on the display. The residual errors are also
used for selecting the variant of strip adjustment according
to independent polynomials for each coordinate. The following
variants of strip adjustment are available:

- without adjustment
- planimetric adjustment
- height adjustment
- planimetric and height adjustment

Following approaches were chosen as polynomials for strip
adjustment:

$$X = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 xy$$
$$Y = b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy$$
$$Z = c_0 + c_1 x + c_2 y + c_3 x^2 + c_4 xy$$

After strip adjustment the residual error at the control points
are indicated on the display, then all strip points are trans-
formed fron the model coordinate system into the ground coordi-
nate system. The subroutine "absolute
orientation" can be called up repeatedly.

2.2.3.3.   Graphical representation of error vectors
at the control points

The residual errors obtained according to the chosen variant
of strip adjustment are represented by this subroutine at
a freely selectable scale (control points and residual errors)
on the plotting table. Using this error vector representation
the operator may choose a different variant of strip adjustment
aftre absolute orientation. Following the kinds of represen-
tation:

- control points
- control points and projection centres
- control points, projection centres and tie points

2.2.3.4.   Calculations of setting values

With this subroutine the setting values of the orientation
elements and basic components are calculated for a chosen

model scale for subsequent plotting of the photographs of
the triangulation strip at analog plotters. The subroutine performs
a computational absolute orientation of each model of the
point coordinates stored during strip measurement to the iden-
tical points of the adjusted strip coordinates. The corrections
for the orientation elements and base components are applied
to the values stored during the dialog of the strip formation
routine.

2.2.2.   GRID program

With this program ground control data can be obtained for
subsequent plotting. A choice can be made between a grid of
lines and a grid of crosses. The scale, size, line spacing,
lettering, etc. are input via dialog.

3. Technology of on-line strip triangulation

Nowadays, aerial triangulation is one of the routine jobs
of photogrammetric departments. Working in technological steps
is quite essential for this kind of task.

3.1.   Project preparation

It is useful to prepare the project for each aerial triangu-
lation to be carried out. In our case, project preparation
 means processing of already existing photographic material
for measurement in the plotter. The preceding technological
steps photo flight planning and signalling project are not
included. Proper project preparation can speed up measurement
of the photographic material in the plotter.
The main steps are:
- Transformation of photo centres from the photo material
  onto the project map with the aid of contoures
- Marking of the required map sheet (processing area) in
  the projection map
- Selection and transformation of control points (signalled
  points or contour points or map control points) in the

projection map. Number of control points depends on number
of models. The individual departments, i.e. the aerial
triangulation programs they use have respective normatives.
For arrangement of control points, special configurations
have to be observed.
- Selection of tie points from model to model and strip to
  strip on the base of the photographs and their transforma-
  tion in the project map.
- Preparation of a "technical design" of aerial triangulation.
  The technical design is a tracing of the data of the project
  map.

  Following data should be included:
  - borders of the processing area
  - map sheet sections
  - all image numbers
  - all planimetric and height points
  - all model tie points
  - additional information such as object designation,
    scale, camera used, etc.

The technical design is required for point transformation
and measurement.

3.2.   Point transformation

For aerial triangulation, signalled control points, contour
marks, or arbitrarily marked points can be used as model tie
points. During project preparation, the areas for the position
of the tie points are selected and marked on the basis of
the photo material. Highest accuracy of point identification
during measurement is acquired by the signalled points. Signal-
ling, however, requires great efford before the flight as
well as high demands on the photo flight navigation. The use
of clearly defined contour marks is much more efficient. These
points are selected at a mirror stereoscope and marked in
paper copies. Additionally, it should be useful to make
sketches for quicker identification of the marks during
measurement.

Accuracy depends on the quality of contour point definition.
In build-up areas, this quality nearly corresponds to that
of the signalled points. When using the arbitrarily marked
points, they are marked with a stereoscopic laser point marker
(e.g. with TRANSMARK) in the predefined areas. Very good accuracy
is acquired if setting errors and machine faults of the point
marker are avoided.

3.3.   Measurement

For measurement of aerial triangulation strips, adaptation
of the stereo plotters of Kombinat VEB Carl Zeiss JENA by
special devices is not necessary.
The control point coordinates under project designation. being
entered and stored, connection to measuring instrument, error
limits and further declarationss are determined in the
MACHINE program.
Prior to measurement of an aerial triangulation strip the
coordinates or correction vectors, resp., for the projection
centres should be determined with CENTRE program. This determi-
nation can be easily done. Due to the various designs of the
stereoplotters, there exist different measuring positions
for the different calibrated principal distances.
Calibration marks on the mark plates
can be used as auxiliary means of setting. For this purpose,
set and register the marks in the right and the left image
with a great and a small projection distance in monocular
mode. The measurement concluded, the mean measured values
in succession, the calculated correction vectors, and the
base components are output on the terminal or on the printer.
Confirmation of the measurement is followed by storage of
the correction vectors for the projection centres. For the
actual strip triangulation, beside the photographs the techni-
cal design is used at the stereo plotter. It comprises all
data required for measuring the stereo models – strip designation,
image numbers for model designation, designations for control
and tie points.

If possible, carry out formation of all models of a triangu-
lation strip with a constant base setting."Mean base" can
be determined during preparation. Prior to actual measurement,
enter orientation data and base components according to the
relative orientation of the photogrammetric model via dialog.
These values are stored in a file for calculation of setting
values.

Measurement of each model is performed in a coordinate system
defined by the projection centres. The coordinates are corrected
by the correction vectors. Before registration of each point
enter the respective designation via dialog. After
measurement of the second and each following model of a strip
residual errors of the model connection in model scale are
indicated in the display. On the basis of these data the eva-
luator can accept the model connection and proceed measurement
with processing of a further model, output the results via
printer, or change them.

During modification there exists the possibility of erasing
points or substitution by single measurements or measurement
 of the entire last measured model. Then the residual error
is indicated again. In case of incorrect double measurements
(error limit specified in MACHINE program) error indication
is performed, measurements of the respective points are elimi-
nated and have to be performed anew. After measurement of
each model you can call up the other part programs (2.2.3.2.,
2.2.3.3., 2.2.3.4.).

During absolute orientation of the aerial triangulation strip
the strip coordinates in model scale of the model measured
first are transformed in the control point coordinate system.
Residual errors at the control points in the State plane coor-
dinate system are indicated on the display.

Thus, you have the additional possibility to adjust the strip
(see 2.2.3.2.).

After this transformation allstrip coordinates are transformed
in State plane coordinates with the correction polynomes deter-
mined during adjustment. The coordinates stored on file can
be directly used as control point file for computer-aided
stereoplotting or for map sheet preparation (2.2.4.).

Graphic representation of the error vectors is an auxiliary
means for evaluation of residual errors for the selection
of the mode of strip adjustment. The subroutine calculation
of setting elements is for calculation, display, and output
via printer of setting values for a desired model scale.

4.   Results

The STRAUS on-line strip triangulation program has been well-
proved in several photogrammetric departments for most
differnt cases of application. All users appreciate the user-
oriented dialog, easy program handling and high efficiency
by quick on-line testing of the results.
Representing the various fields of application, we wish to
make you acquainted with the program utilisation for photogram-
metric control point determination in open cast surveying.
In most lignite open casts in the GDR calculation of cubic
contents as well as mining engineering safety control are
 performed by methods of aerial photograph plotting. For this
purpose, control points have to be determined in each model.
Generally, control points of an open cast are permanently
 signalled and determined in geodetic terms. In Winter, several
persons are required immediately before the photoflight to
hold the respective signals for each model visible from above.
For one year now we have been using the STRAUS on-line strip
triangulation program in the DZT 90 x 120/RGS computer-aided
stereoplotting system for control point determination during
winter.
Average strip length for the open casts is 5 to 7 models.
An accuracy of m'xy=25µm and m'z=12µm is acquired with wide-
angle photographs and a scale of abt. 1 : 9000. Exclusively
unsignalled terrain points are used as model tie points.
Results are improved by using arbitrarily marked tie points
(e.g. with TRANSMARK). The accuracies acquired that way are
sufficient for the purpose of stereoscopic model restitution
(graphic and digital) for mass determination and mining engineering
safety control. Signalled points geometrically spread over

the entire open cast served as control marks. For strip adjust-
ment, 2 points at each the strip beginning, middle, and end
are used. Using the STRAUS on-line strip triangulation program
for control point determination in GDR lignite open casts
during Winter saves cost and manpower. Performing the triangu-
lation requires 20...30 min/model on average.

Table 1. Printout. Determination of the setting elements (strip, model scale, model)

STREIFEN: STREIFEN.1

MODELLMASZSTAB = 1 : 12500

MODELL: 156–158

BX = 169.100 MM	BY = 28.998 MM	BZ = 30.463 MM
PHIL = 11.688	PHIR = 11.488	
OMEL = 8.760	OMER = 8.930	
KAPL = 4.600	KAPR = 4.450	

MODELL: 158–160

BX = 184.072 MM	BY = 28.960 MM	BZ = 28.149 MM
PHIL = 11.884	PHIR = 11.904	
OMEL = 8.568	OMER = 7.748	
KAPL = 3.400	KAPR = 6.800	

MODELL: 160–162

BX = 188.346 MM	BY = 28.685 MM	BZ = 29.712 MM
PHIL = 11.870	PHIR = 12.120	
OMEL = 9.308	OMER = 8.328	
KAPL = 3.200	KAPR = 0.350	

MODELL: 162–164

BX = 186.137 MM	BY = 34.582 MM	BZ = 30.016 MM
PHIL = 11.656	PHIR = 11.316	
OMEL = 10.329	OMER = 10.409	
KAPL = –0.250	KAPR = 0.300	

MODELL: 164–166

BX = 186.962 MM	BY = 33.035 MM	BZ = 29.550 MM
PHIL = 12.013	PHIR = 12.343	
OMEL = 10.328	OMER = 10.728	
KAPL = 1.700	KAPR = 0.300	

MODELL: 166–168

BX = 185.262 MM	BY = 33.403 MM	BZ = 29.940 MM
PHIL = 11.704	PHIR = 10.874	
OMEL = 9.990	OMER = 10.860	
KAPL = 1.900	KAPR = 3.900	