

INTRODUCTION TO THE A P Y SYSTEM VERSION 4e

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ABSTRACT

The A P Y is an analytical photogrammetric system with BINOCULAR superposition of an existing map, or satellite imagery, and graphically displayed data on the stereoscopic model to facilitate change detections, graphic revision and digital data updates. Special attention is drawn to metric and semantic needs in topographic and thematic data compilation, such as: Densification of control points, Orientation and measurement of 2-D photos, maps, and 3-D models, Interpretation for data compilation and revision in layers, Data exchange with L.I.S. & G.I.S.

Topographic maps and data bases will soon cover the world adequately. The future task will be the completion and revision of these data in digital form. The A P Y (Analytical Photogram-meter by Yzerman) is a technological development for this purpose, and available since 1987. The system can be used for topographic and thematic mapping, regional and urban planning; including natural resources and environmental survey & management for roads, energy, water, agriculture, forestry, wildlife, etc. The accuracy is about 0.1mm rmse at compilation scale. 2-D measurements on prints can be made, also for bundle block adjustment, thereby replacing the old slotted templet method.

Computer control can serve this robust, portable, and LOW COST design to compile digital data in 3-D with feature descriptions. The main menu of the A P Y programs appears automatically upon switch on. The user selects the desired item, and the interactive software guides the operator step by step. The parallaxes between photos and map in at least four control spots are eliminated in binocular superposition. The computer calculates the absolute orientation of each photo, and introduces parallax corections to the precision optics in real time. Stereo measurements can then be made in ANALYTICAL PERSPECTIVES. Curved line points can be sampled progressively, line points searched; lines split; data automatically saved; distances, inclinations and areas calculated; symbols and texts added; data deleted; displayed compilation verified in binocular superposition; check plots printed; and margin files created. There is an adaptable program to exchange data with L.I.S. and G.I.S., and to drive drafting plotters.

The optical diagram illustrates the two PHOTOS (1), the two zoom systems (2), and the optical train with other elements through which they can be observed in stereo at the eyepieces (3). The MAP (4) on the digitiser tablet is also observed through a zoom system (5), and a beam splitter (6). The path then continues left and right via the beam unifiers (7) to the eyepieces. As a result, the map can be seen BINOCULARLY SUPERPOSED on the photo images, and therefore with the photographic stereo model. Between each photo and the beam unifiers is a pair of optical plates (8). One plate can turn around an horizontal axis, the other around a vertical axis, thus enabling to shift the photo images in vertical and horizontal directions. These means allow to eliminate the prevalent parallaxes between the coresponding photo and map details. The injection (9) of the GRAPHIC display via the beam splitter (6) allows the BINOCULAR SUPERPOSITION of compiled data on the existing map, as well as on the stereoscopic model of the photos. This optical design offers interesting geometrical and therefore analytical consequences.

Colinearity Conditions (a)

$$(x-x_0) = -c \frac{a_{11}(X-X_0) + a_{21}(Y-Y_0) + a_{31}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)}$$

$$(y-y_0) = -c \frac{a_{12}(X-X_0) + a_{22}(Y-Y_0) + a_{32}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)}$$

Superposition Conditions (b)

$$(x-x_0) = -s_x(X-X_0) + p_x$$

$$(y-y_0) = -s_y(Y-Y_0) + p_y$$

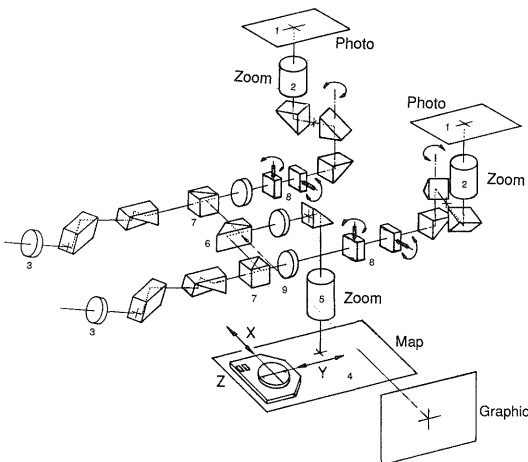
A.P.Y. Parallax Conditions (c)

$$p_x = s_x(X-X_0) - c \frac{a_{11}(X-X_0) + a_{21}(Y-Y_0) + a_{31}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)}$$

$$p_y = s_y(Y-Y_0) - c \frac{a_{12}(X-X_0) + a_{22}(Y-Y_0) + a_{32}(Z-Z_0)}{a_{13}(X-X_0) + a_{23}(Y-Y_0) + a_{33}(Z-Z_0)}$$

A P Y ALGORITHMS

The optical plates satisfy the A P Y Parallax Conditions (c), which involve the analytical Colinearity Condition (a) and the Superposition Condition (b). (a) is the colinearity of the terrain point with the projection centre and its coresponding point in the photo. The photo coordinates equal an expression in ground coordinates and the cofactors, which are a function of the roll, pitch and yaw of the camera. (b) is



A P Y OPTICS

the superposition of the map on the photo. The photo coordinates equal the scaled ground coordinates plus a parallax, which is again due to the roll, pitch and yaw of the camera, and the height differences in the terrain. The A P Y Parallax Conditions (c) are obtained by the elimination of the photo coordinates from (a) and (b). For scanned imagery:  $Y_0$  is set equal  $Y$ , or  $Y - Y_0 = 0$ . The entire photo stage can be positioned to view the area of the model to be interpreted, compiled or revised. A shutter allows to see the floating mark on the map, or in the stereoscopic model. The floating mark is moved by hand over the map, and its position thereby digitised. The height is changed up or down by two push buttons. The Computer receives these positions and heights, and controls four stepper motors. These motors rotate two pairs of geared optical plates, in order to shift the beam from each photo in x and y direction. The parallaxes between each photo and the corresponding map point are thus eliminated. The height resolution, by means of the step-wise driven optical plates, is about 2.5 times better than the digitised planimetry! The residual height parallaxes are therefore adjusted by the bilinear condition:  $dpZ = Ax + By + Cxy + D$ . The factor A adjusts the model in the x direction, the B in the y direction, the C for differential omega warp, and D for the consequential bias error in height.

#### A P Y DATABASE FORMAT.

The A P Y System allows for digitising and filing of: point numbers, X- Y- Z-coordinates; followed by either point codes (symbol file), four references to neighbouring points (line file), or text (text file) in each map layer.

The point numbers have 4 digits, the X- Y- Z-coordinates respectively 9, 9, and 6 digits (in cm) In addition, the symbols have 2 digits for a code; the line points have also 2 digits for a code, and of course 4 digits for each reference to neighbouring points; the texts can be 24 alphanumeric characters long.

The A P Y System has therefore a POINT related data base in binary code, to describe 1000 symbols, 10000 line points with their branches referenced, and 500 texts per layer.

#### DATA TRANSFER

The A P Y transfer program DATA EXCHANGE offers (1) "Make ASCII file" from which other file formats can be made by the user. However, (3) makes ARC/INFO files, and (5) makes DXF files.

The ARC/INFO user can generate line and point coverages, from which Triangulated Irregular Network, slope and aspect, and 3-D views can be produced Conversely, (2) will Read ASCII files into the A P Y format. (4) reads ARC/INFO files with line points in string format only. As a consequence, the A P Y software can not calculate areas anymore in its COMPILATION menu. Data can thus be transferred from a GIS for interpretation, orientation, updating, verification of the 3-D data by the A P Y System.

#### FEASIBILITIES

Photos of any focal length, and size up to 300x300 mm., can be used. The A P Y concept implies to move the floating mark around in the field of vision, where at least four control points should be available in the standard orientation areas. These can be the lateral control spots only (entire model), or two lateral and two near vertical spots (half a model). The A P Y orientation software calculates the coordinates of the projection centres and also the rotations omega and phi.

Sometimes a map lacks control spots. Measurements for a densification of ground control can be made with the A P Y System. Photo nr 1 should be placed on the left stage, nr 2 on the digitising tablet, and nr 3 on the right stage. The central- and lateral-points of each photo can be transferred stereoscopically to nr 2 on the digitising tablet, and these nine points measured there. Likewise using the photos 2, 3, and 4, etc. The sets of nine coordinates groupes in each photo can be related to the adjacent photos and adjusted with a PC compatible bundle adjustment program. Additional points with their height can also be compiled in an entire or half model with the symbol 00, which is a tiny cross and its height.

A control points- and or grid-plot can be made with the A P Y System. Model sections a small as 40mm. diameter can then be oriented and compiled from with a height accuracy of 0.02% of the flying height

Graphical annotations can be made on the map, or an overlay, exploiting local superposition of the model. There is an adequate range of zoom objectives available for practically all map/photo scale ratios. The photos can be placed in the viewer for stereoscopic interpretation, while only the "map" is oriented to digitise the details, coded with symbols and texts, edited with the aid of the superposed graphic screen.

#### OPERATION

The A P Y System can be operated without computer experience. Upon switching on, the apystart program is called up automatically, which presents the MAIN MENU of the user programs: File Editing, Orientation, Compilation, Print & Plot, Symbol Creation, and Date & Time. The first three programs are to be used in their order.

FILE EDITING prepares for the orientation. The identification of the photos, their principal distance, whether or not scan imagery must be entered here. X, Y, and/or Z of the projection centres, omega and phi, can be entered if available. Entered control points can be called up later in the orientation. The identifier of the map, and the compilation scale, which should be larger than 0.1mm./ground accuracy, must also be entered.

Compilation is possible in different layers. For example file IDENTIFICATION with layer extensions: .c, .e, .h, .r, etc. for control, elevations, hydrography, roads, etc. Orient with map file ID.c ; compile ID.e data; rename ID.c into ID.e; open a new file ID.c; compile ID.h data; rename ID.c into ID.h; etc., etc.

An approximate orientation may be prepared as follow: Estimate the average photo scale by comparing the distances of two points in the map. Calculate  $Z_0 = (\text{focal distance}/\text{photoscale}) + \text{average point heights}$ . Mark up the photo centres. Superpose the central photo area on the oriented map in the viewer, and measure the approximate  $X_0$ ,  $Y_0$  coordinates of the centres. Enter  $X_0$ ,  $Y_0$ ,  $Z_0$  in the photo file. If control spots can not be found in four standard orientation areas, then enter  $\sin.\omega$  and  $\sin.\phi = 0.0001$ . Upon orientation of the photos, one can compile in approximated central projections. Any residual parallaxes can be eliminated locally.

ORIENTATION prepares for the Compilation. The map can be oriented only, or with the photos. The transformation from the tablet to ground coordinates can be conformal, affine, or bilinear. The conformal mode requires at least two points, each

being measured twice. The affine mode requires at least three different points, and the bilinear mode requires all four points to be different. If only ground coordinates are known of identifiable photo points, one can choose the conformal map transformation; enter the mark position twice at each of two points in the photos. Existing map data will then be displayed on the graphic screen, and the mark can be set to read the proper ground coordinates of all control points on the monitor, or to coincide the screen cross-hairs with the displayed details. The x- and y-parallaxes of the corresponding photo points can then be eliminated for the orientation of the stereo model. The affine transformation will correct most shrinkage of the paper map. The bilinear transformation improves the accuracy of the digitising paper prints for subsequent block adjustment. It also allows 2-D compilations within matching quadrangles directly from a photo, in stereoscopy with its mates. These quadrangles may compose a polyhedrous (facettes) terrain, and require "map" orientations only.

The object of the photo orientation is to determine the parameters for the real time loop to maintain colinearity of the photo points with the projection centres and the corresponding ground positions. The orientation procedure is automatically limited to determine the yet unknown parameters.

An approximate superposition of the photos and the map is instructed step by step on the monitor. The parallaxes between photos and map are thus minimised, while the following analytical solution will take care of a precise point-wise matching. In addition to visiting at least four control spots in the map and zeroing the parallaxes with the photos, two stage grid crosses have to be visited in each photo for the stage/tablet scale ratio, and one cross in each photo twice to calibrate the optical plate rotations. The calculations of the A P Y parallax equations resolves then the colinearity- and superposition-parameters. The control point number, their coordinates and residual errors, as well as the root mean squared error in position are displayed. Points can now be rejected or added, followed by a recalculation. The user is then asked to accept, or reject and try to improve the colinearity conditions. The orientations come to an end, when the transfer of the parameters to the temporary orientation file is approved, and the operator may proceed to the compilation.

#### COMPILATION

Compilation is controlled by the 27 buttons pad, which is integrated with the digitising mark. The DESCRIPTIVES button provides an item number for a symbol, line or text. The symbol mode suggests a PROCEED choice to list the 99 symbols, and/or a symbol number choice. The number and name will be displayed on the monitor, and a choice of DELETE offers to rechoose the number, to place the mark and ENTER, or to PROCEED to the compilation menu. The line mode offers to choose a decimal rounding down of the height read-out, a two digit line code, the SAMPLE option, to SEARCH a line point, ENTER new line points, PROCEED to leave the line open, and PROCEED again to the compilation menu. The SAMPLE option is based on a limited "across track error" concept in navigation. Upon entering two points, defining the first track, line points will be sampled automatically, also allowing the ENTER, SEARCH, and PROCEED functions. The text mode offers to type the text with the keyboard, and ENTER this text to the right of a +

mark, as an attribute to its X, Y, Z coordinates. The L S (Line Split) button provides to interpolate a new point in an existing line side. The AREA button offers to calculate, upon entering two neighbouring points of a line in a clock-wise sense. It will also check if, and where a line is not closed. The DHI button allows to measure Distance, Height, and Inclination between two points. The DELETE button offers to choose an item number for symbol, line, or text, then place the cross-hairs and ENTER, or PROCEED to the menu. The PROCEED menu shows the number and % of data compiled in the files, and offers to choose an item number to set the scale factor of the graphic display, to eliminate parallaxes, adjust cross-hairs scale, terminate compilation, or return to the compilation menu. The scale factor can be chosen at random from 0.25 to 25x. A factor = 1x will cause the graphic screen to be superposed on the map. The eliminate parallax function actually changes the zero position of the correction plates. This may be desirable: 1) upon a main power cut, 2) while compiling on an oriented map only, aided by stereoscopic interpretation, 3) while compiling from distorted photos or map. There is an automatic "save data" upon 50 entries and a PROCEED signal. A margin file is created, containing all line points without a forward or backward reference, so that line can be joined across a map margin.

#### PRINT & PLOT

Print & Plot allows a print out of the map file, consisting of a symbol legend, symbols sorted according to their attribute code, lines points with forward, backward and side point references, and texts. It allows for vector plotting on a flat bed or drum plotter, and a neat NEC Pin-Plot. There is a PLOTTER.DEF file to set the plotter parameters as required.

#### DATA EXCHANGE

Data Exchange allows the loading of already compiled data in the area and the transfer of the revised and completed data to another computer. Bundle measurements are compiled in the text mode. This format can be transformed here into a Bundle file for direct use in the BLUH or PAT-B programs.

#### SYMBOL CREATION

Symbol Creation allows the user to design specific symbols. A list of 99 named items is presented to choose from. The symbol name can be given or changed, and a 15x15 chessboard representing the 15x15 pixels is displayed. The symbol 00 is reserved for the spot height, and can not be touched. The direction keys cause a displacement of the cross-hairs over the fields, while the + button paints, and the - button clears the field. The created symbol appears then for approval. All symbols are finally saved and immediately available in the compilation program. In fact, symbols can be changed or added while interrupting the compilation program.

