Photogrammetric Week'93 Eds. D. Fritsch / D. Hobbie, Wichmann, Karlsruhe, 1993.

Raster output of photogrammetric data

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ABSTRACT

Raster plotters have become a suitable means to produce quality graphic output from digital map data. Photogrammetric data usually must be subjected to a number of cartographic procedures in order to achieve good results. Different types of source data may have to be combined and refined, a step that may involve a considerable additional effort. Map symbolization can take place either in vector or in raster mode. Once all vector data are converted to raster, all features of the plot files are ready to be specified in terms of colour, screen percentages and orientation. The screening technology allows for a series of variants, some based on the experiences of conventional reproduction techniques, others making use of the specific properties of raster plotter software and hardware. A critical factor is the resolution needed to guarantee fine linework, easily legible lettering and a wide range of colour tints.

1. INTRODUCTION

The result of photogrammetric restitutions is either a graphic manuscript or a digital data base, that can be displayed on the screen of a workstation. If a large number of hard copies are needed the conventional procedure consists in cartographic and reproduction processes like fair drawing or scribing all the line work on the basis of the manuscript, deriving masks for the area tints and adding lettering in a stick-up process. The originals thus prepared are assembled in a copying process on final films ready for printing on a press or for copying using a copier. If however one can switch to or base on digital data, in principal the path is open to digital plotters. The question is then, what further steps are involved in the production of appropriate output. The answer depends on the type and number of colours of the map features to be represented, on the degree of quality aimed at and on the number of copies to be delivered. In recent years we observe a move away from pen plotters and towards a variety of raster plotters. This move is mainly due to the fact that the pen or vector plotter can cope successfully only with line work, while the raster plotter renders also screened area tints or shadings and occasionally even halftones.
We cannot expect photogrammetric data being clean for high quality output and completely attributed according to cartographic requirements. Therefore we have to discuss necessary cartographic refinement of the restituted or digitized vector data, local displacements and even generalization cannot be entirely excluded. Another essential step is vector-to-raster-conversion, followed by specifying the final output components. Finally we will have to look into different hardware and software solutions and their impact on plotting raster data.

2. UP-GRADING PHOTOGRAMMETRIC DATA

2.1 Various types of photogrammetric data

We have to consider as source data more than just one type of photogrammetric data, depending on the photogrammetric processes that were used to create the data files. Let us suppose that the final goal is to output some topographic features, like road and railway networks, buildings, contour lines, hydrographic networks, land use mosaics, names, spot heights and coordinate grid or graticule. Any other thematic features gathered by photogrammetric processes can be handled accordingly, due to the fact that the geometric types (line work, point symbols, area tints or patterns

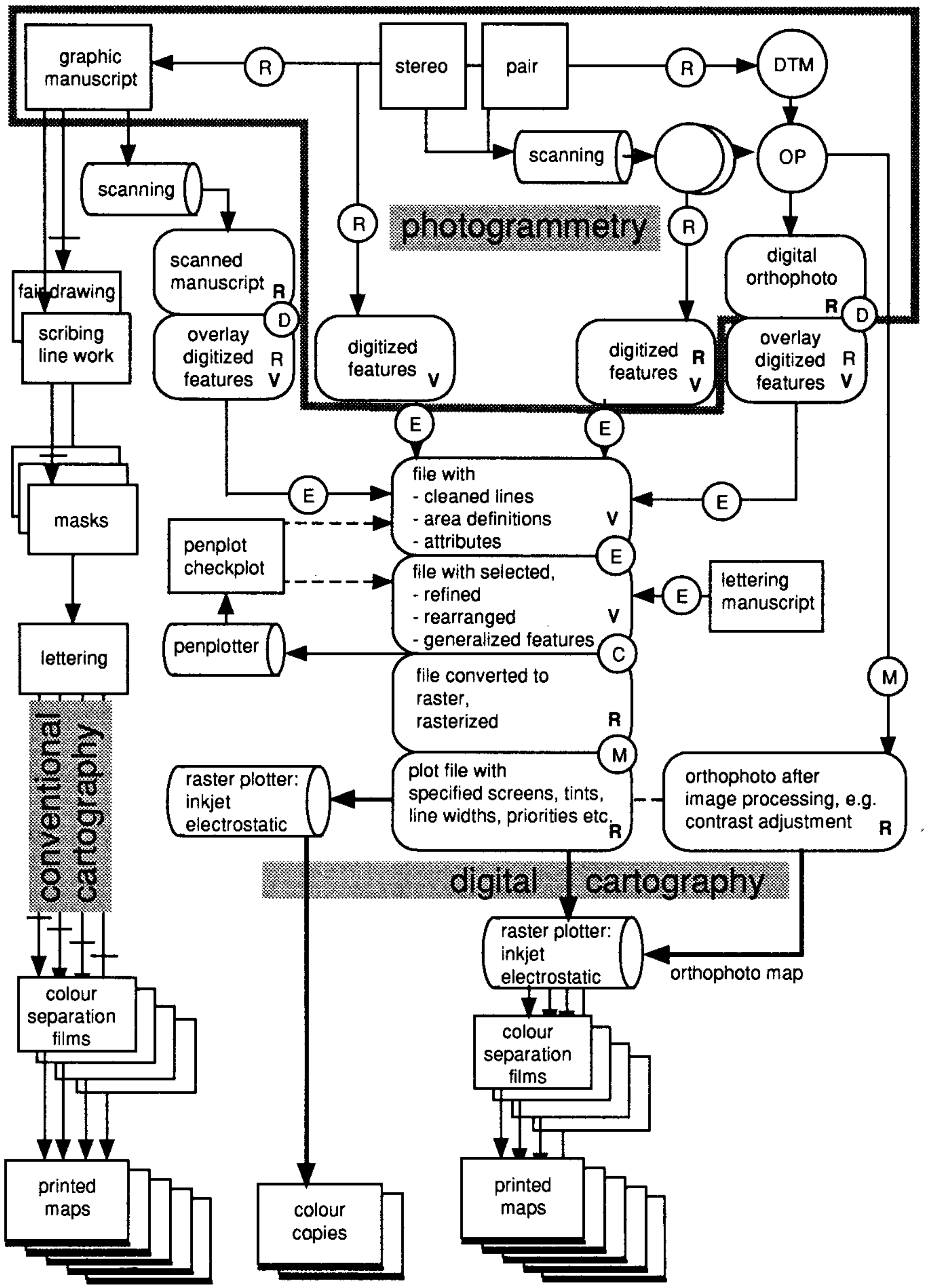

Figure 1: Flow diagram for the output of photogrammetric data.

and lettering) will be somehow the same. In a more genereal approach we should, however, include also DTM models, as well as analogue and digital orthophoto images with their entirely different image structures.
Refering to fig.1 photogrammetric source data may be produced by different methods, namely by

a) analogue stereo restitution (R) of the original stereo model, resulting in a graphic manuscript
b) digitizing from the stereo model and producing the graphic manuscript by subsequent plotting (not included in this figure)
c) digitizing from the stereo model in vector format (V) and displaying and storing digital data
d) scanning the original stereo pair producing raster data (R) and subsequent by digitizing vector data (V) in an overlay mode on the stereo screen
e) sampling height points, profiling or contouring the stereo model to obtain a DTM
f) producing a digital orthophoto in raster format from the scanned imagery (d) on the basis of the DTM (e)
g) scanning the manuscripts plotted under a) or b), resulting in binary raster data (might be considered as a cartographic process)

2.2 Preference for one of the photogrammetric procedures

The most straightforward solution seems to be variant c), but experiences have shown that it may be quite demanding for the operator and time-consuming to achieve an almost perfect data set that needs only few further treatment. It is hard for him to hold control over every single element of a map. Some lines may be not smooth enough. Dashed lines may have uncomplete corners. It may be difficult to judge minimum dimensions in the photographic image, creating this way plot with to much congestion among symbols. Roads that will be rendered finally as double lines may cause some displacements of houses e.g. which are not obvious at this stage. Therefore a two step solution, leaving the finishing procedure to the cartographer, may be a better approach.

2.3 Data formats

Due to the above range of methods the cartographic process starts with different kinds of data,

- analogue graphic data; drawings with pencils or ink, scribed negatives on foils or film,
- digital vector data; polygones and cells, eventually also arcs. Depending on the system used this source data contains different ranges of attributes (line widths, line patterns, curve functions, area fillings and patterns) or is characterized by different degrees of topology,
- digital binary raster data, usually as run length encoded files (rle-data),
- digital raster data, characterized e.g. by a grey scale of 256 steps, 8-bit monochrome continuous-tone data (cot-data) or 24 bits for colour data (rgb-data).

It is evident that the cartographic workstation and the software used must allow for active layers for both types of raster and for vector data to handle these four types of data .

2.4 Raster to vector conversion, overlay digitizing

The binary raster files, results of the scanning processes, may have to be converted to vector files, which give more flexibility for symbolization and allow for attributing different map features.

Advanced vectorizing software allows to discriminate features by their different line widths and colours. Usually some amount of interactive cleaning and verification, original raster image in the background and converted vector image in the foreground on the screen, cannot be avoided. The necessary effort depends on the complexity of the map detail. Whenever available a separate film per each feature class should be scanned and vectorized.
The alternative is to digitize new vector data on top of the scanned raster image in the background of the screen. The display allows to zoom the two images in and out as needs arise. On the other hand it may be difficult to make graphically sound and consistant judgements, if scale varies too often.

2.5 Integration of data of different origin

Whatever procedure has been followed so far, the aim must be to achieve a complete, homogenious and fully structured database. Their geometry may be partly multi-feature coded. If this database serves as a digital landscape model (DLM) or GIS-model, topology may be required, especially for data analysis and data up-dating. For pure mapping purposes it can be questioned whether topologically structured data are really needed and an advantage.
The minimum requirements can be described as follows: Lines must be cleaned, i.d. having no overshoots or undershoots within a linear network. Areas must be closed and unambiguously defined. The problem of islands within an area must be kept in mind for further treatment. Finally all data must be clearly identified by their attributes, so that data can be selected by feature.

3. ESTABLISHING A DIGITAL CARTOGRAPHIC MODEL, MAP EDITING

3.1 Map conception

A photogrammetric database allows for more than just this one and only map. When conceiving cartographic output, one has to choose among a number of variables, namely map scale, section of the data base, features to be represented and their symbolization, including size or line width, texture, colour etc. as well as map format and layout.
These decisions determine how the GIS-data model has to be processed, refined and generalized. In fact quite often the photogrammetric manuscript is at a larger scale or the files captured in digital form are much too detailed for the map to be published, in which case a generalization process will be unavoidable. The question remains whether each time a map has to be derived a new digital cartographic model (DCM) must be developed, because each of them allows only within narrow limits for scale, feature and symbol variation.

3.2 Selecting minimal dimensions and thresholds

When the above decisions are taken, the next step is to become aware of the minimal dimensions and thresholds, as e.g. minimal amplitude of a line or of a double line, minimum edges along building outlines or of a house symbol. Another threshold value is the maximum length of a secant in an arc, that will be shown by a polygone. Equally the length L of edges in polygones which are supposed to represent smoothly curved lines are to be determined (fig.2). We derived empirically that L may be approximated by the following function of the curvature radius R:

$$L_{[mm]} = 0{,}2 * R^{0{,}7}{}_{[mm]}$$

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e.g. a 4 mm radius may be represented by secants of 0,5 mm.

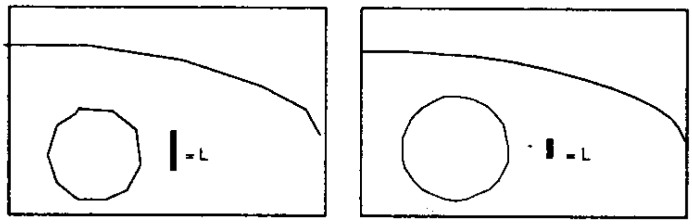

Figure 2: Determining the threshold of the maximum length of polygone edges for smooth curves.

As radii may vary considerably one might choose a rather small L. But when L approaches the grid resolution the lines may become rugged. Curve or smoothing functions often allow for a variation of this parameter.

3.3 Line simplification, smoothing and interpolation

If in photogrammetry line features were traced in a point or tracking mode without using a curve function, often some refinement is needed, even when no scale change is involved. A large number of algorithms compete with each other under different terms as e.g. line smoothing, approximation, filtering, etc.

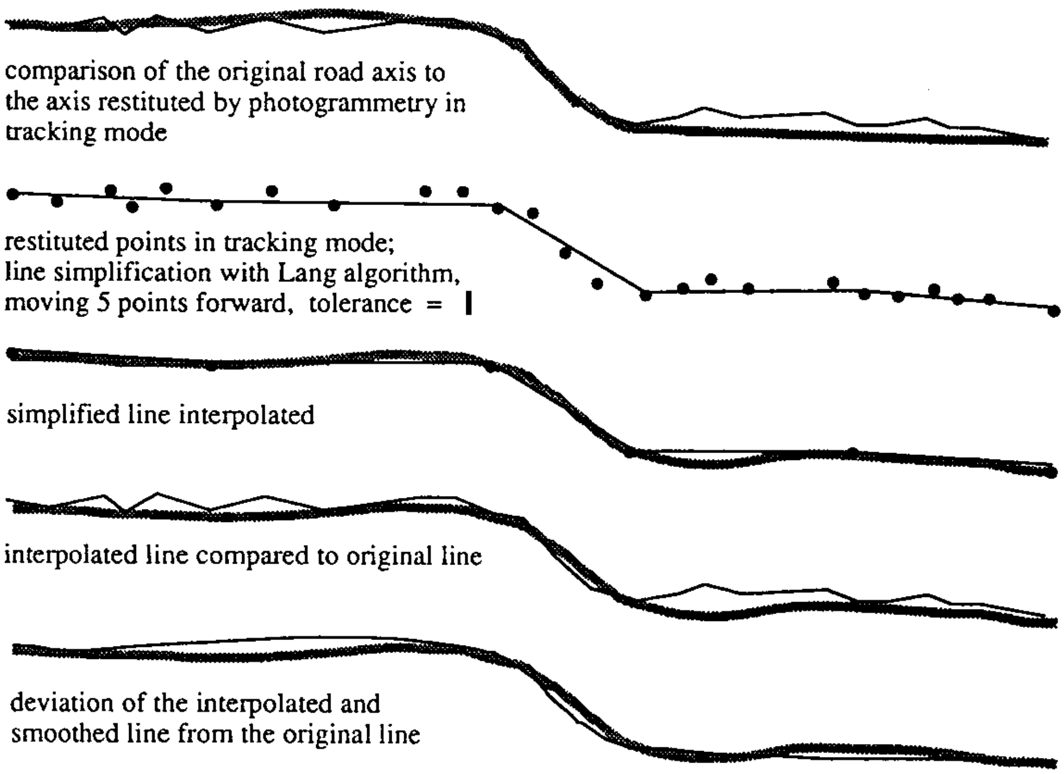

Figure 3: Line simplified in the first and interpolated in the second step.

What is the best approach in each case depends on the characteristics of the source data. If points are dense and the lines too rugged, it is recommended to start with searching for the critical points

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of each line and then in a second step interpolating again points between these hinge points. In fig.3 this procedure is illustrated with a piece of road axis restituted in a tracking mode. A vectorized manuscript often shows similar characterstics.
In fig.3 a piece of a road axis was simplified first using the Lang algorithm. Through the remaining points a smoothed line was calculated by cubic interpolation. The result compared to the precise original shows a typical effect of such interpolation procedures: The curve swings through the hinge points. The typical characteristics of a road axis, a combination of straight tangents and curves is not retained, unless special measures are taken, as e.g. splitting the axis and attributing different geometries with identical tangents in the connecting points. Similar problems are encountered with other line types. In fig.4 the problem is to retain a sharp bend in a contour line. In this case the interpolated line may be constraint by two additional points near the sharp turns. Another solution would be a piecewise interpolation of the contour polygone. Taking care of all such characteristics causes quite an effort in interactive editing.

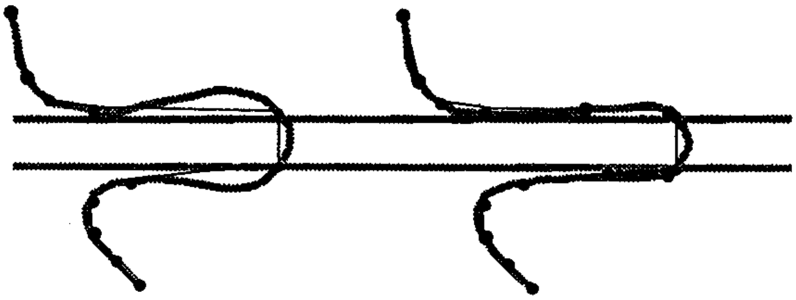

Figure 4: Effect of different point selections on the interpolated curve.

3.4 Overlay digitizing the final map image

In many cases the geometry of the final map image is quite different from the one of the source data, especially when the generalization imposes shifts and other changes from the original position because of overlapping or congested areas. According to our experiences it is then often easier to redigitize the new map in an overlay mode on the graphic screen, whereby one can take care of all implications. Fig.5 illustrates the procedure for improving a photogrammetric plot with a winding footpath for output in a school atlas map.

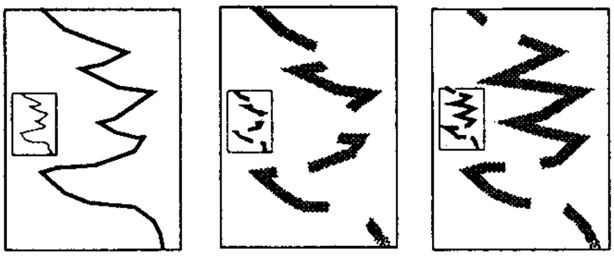

Figure 5: Footpath that lost most bends when symbolized with a dashed line and has to be redigitized for improved representation.

During such procedures it is important to dispose of the final symbolization, step by step, so that each consecutive element can be adjusted to the previous ones. It may be achieved by rasterizing element by element provisionally or by attributing to point symbols and line work the final line pattern and widths.

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3.5 Other map editing procedures in vector mode

Whenever the geometry changes for certain map elements, most certainly others have to be adjusted to this new position. A typical example is matching the woodland outlines to the roads symbolized in the map by double lines (see fig.6). Outlines running along the road axis may be masked out at a later stage. If some areas have to be modified or slightly enlarged in order to respect the minimal dimensions or retain certain characteristics, an interactive approach will be necessary. The same would apply to settlement areas. Another procedure that is favourably executed in vector mode is lettering. But here again there is a need to dispose not only of the map elements but also of the type in final form, font, size and extension, in order to adjust it to the other map content.

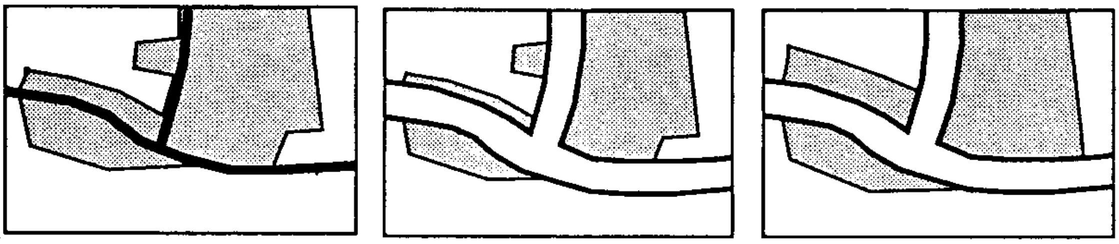

Figure 6: Woodland area and road axis; represented by a double line and leaving too small parcels of woodland, improved by interactive editing of the woodland outlines.

3.6 Symbolization in vector or in raster mode ?

Point symbols, lines textures and area patterns may be symbolized either in vector or in raster mode. A vector symbol can be moved and rescaled more easily. But here again it is important to be able to display them in their final form for coordination with all other symbols. Ideally one disposes of a rasterized version of the map so far edited as a background image on the screen and of the vector version in the foreground. Cartographic editing software usually allows for the definition of an infinity of line symbols, double lines, dashed lines and any combinations. A facility implemented only recently in editing systems is to evenly distribute dashed elements between given points by scaling the pattern elements slightly otherwise between such corners (fig.7). With such a feature corners are rendered more prominently.

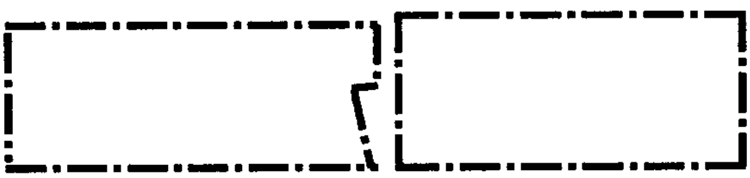

Figure 7: Unfavorable distribution of the pattern elements to the left; clear angles to the right.

Area patterns as well can be defined in vector or in raster mode (fig.8). If a regular pattern looks too artificial, the individual symbols of a pattern can be moved around, making use of a random generator.

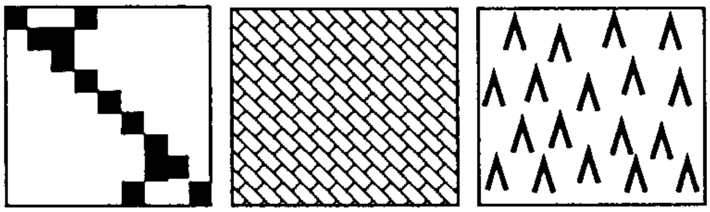

Figure 8: Raster cell for area pattern and random distributed symbols.

4. RASTERIZATION

This term stands for conversion of vector data to raster data. As the final plot bases entirely on raster data, this conversion step has to be performed earlier or later, depending on the system facilities. Some systems can only handle raster files at the plotting stage, others accept a mixture of raster and vector files. The advantage of the latter is that screen tints need not be fully rasterized, thus saving a large amount of storage.

4.1 Rasterization by the brush method

One method is to travel along the vector edge with a set of raster pixels, often refered to as brush. Each pixel of the final raster matrix that is touched by stepping the brush at least by half of its area is given the value of the corresponding pixel of the brush. Using e.g. a plot resolution of 25 mm, a fine line is built with a brush that is 4 to 5 pixels wide. In a simple version the brush is not rotated but only translated along the vector. To maintain a certain line width a dot as round as possible is needed. Figure 9 shows considerable variation in line width depending on the form of the brush. The finer the resolution the less variation has to be expected.

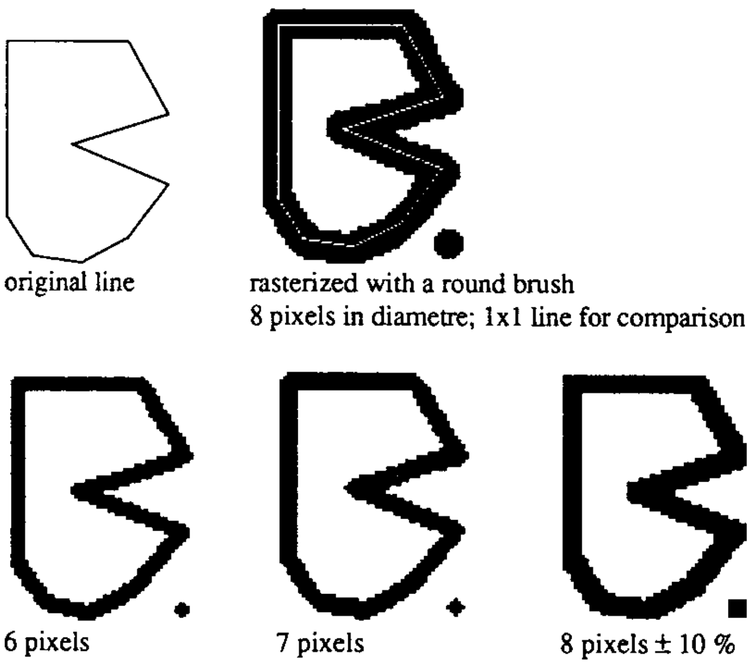

Figure 9: Rasterization with different brushes and their influence on line widths.

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4.2 Rasterization by the outline method

In another rasterization method first the vectors of the outlines of the symbols or lines are calculated. In a second step the outlined areas are filled with pixels (fig.10) whenever a pixel center is inside the outlines. We must realize that rasterized lines and outlines will never be as constant in line width as on a vector plotter and affected also by the alising effect.

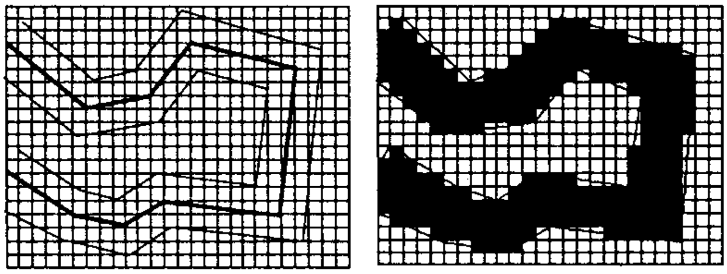

Figure 10: Rasterization by construction of the outlines in a first step and filling in pixels in a second.

If each edge of a polygone is rasterized as a rectangle with the desired line width, polygones with angles that deviate considerably from straight ones show lacunes. They may be closed by adding elements in critical corners, squares or half cercles. Figure 11 illustrates such a facility, which is especially needed in polygones with broad lines or bands.

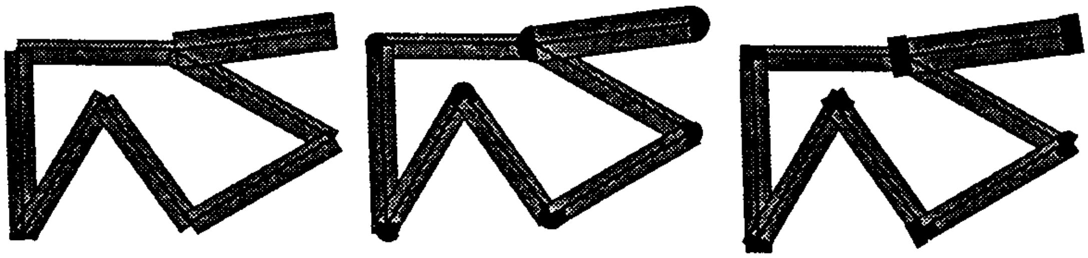

Figure 11: Closing lacunes with additional elements.

In some cases it may be advantageous to compose symbols using Boolean operations. Figure 12 shows the manuscript version of a road network that is to be rendered in double lines. The polygones are smoothed, enlarged to the final width of the double lines and filled with black pixels. In a second version the line width is equal to the spacing between the two lines and filled with opaque white pixels. If the two files are superimposed, the remaining image consists of the envisaged road network in double lines with junctions opened automatically.

5. PLOT SPECIFICATIONS

For each file final specifications have to be made. Each of them is given a priority within the whole range of levels. Furthermore it must be decided whether a level is masked out in all underlaying levels, as e.g. a symbol with white filling, or overprints them. Highest priority, the top level may be given e.g. to the text file that overprints in black all other files. Each feature must be defined in screen percentages of printing colours. For each of them a screen angle and a screen interval is to be fixed. All these informations are collected in the specification table.

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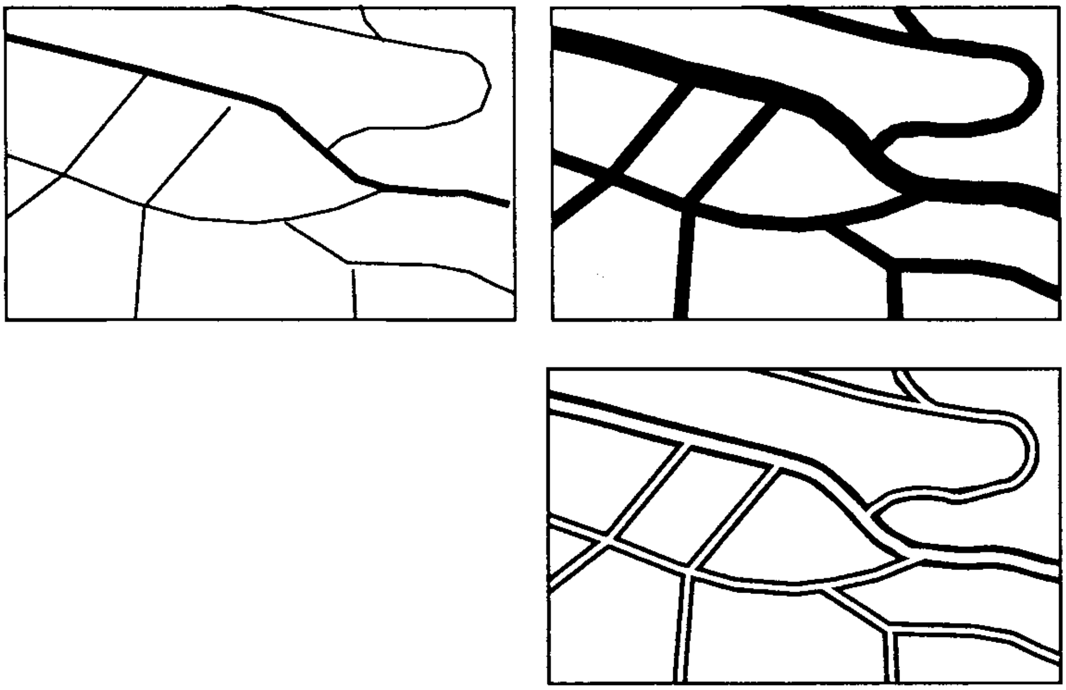

Figure 12: Road axes in the photogrammetric manuscriptsmoothed, rasterized in black and white with two different line widths, resulting in a rasterized double line.

6. RASTER PLOTTING

6.1 Raster plotters

There is a large number of raster plotters differenciating in items like paper or film format, resolution, plotting speed, printing technology, supported data format. The laserrasterplotter uses a laser as light source. The laser beam passes through a round or squared aperture which can be varied in dimension continuously or in fixed intervals. The reprographic film fixed by vacuum on or in a drum or on a flat bed is exposed either to always the same amount of light per pixel, resulting in a black and white image, or with a light varying intensity, resulting in a range of tones. In the recent development of laserplotters the tendency was to speed-up plotting times by using 8 or 24 arrays of laser beams or reduce the masses to be moved. Resolution goes as far as 3600 dpi, equal to 1400 dots per cm with pixel sizes of 0,007 mm.
On the laserplotters a set of colour separated films is exposed, as needed for the subsequent offset printing process. There are, however, requirements to produce on raster plotters directly multicoloured prints, originally in small quantities for preproofing the maps or as work sheets. One may distinguish between screen shots, that plot what is visible on the display and only with the resolution of the display, and real raster plots of vector and raster files. Various electrostatic and inkjet printing technologies have been developed for this purpose. An inkjet printer e.g. produces droplets that can vary very precisely in sizes down to 0,015 mm. The four standard colours are printed in one and the same run.

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6.2 Conventional screen angles and the Moiré-effect

Different colour tints for areas and toned down lines are realized with screens of variable coverage, angles, forms and intervals. The easiest to produce was so far a master screen with cells that are regularily repeated in two orthogonal directions. This principle is generally applied for screens used in reproduction processes. In conventional cartography colour tints are built up with a mask for each area feature class and a range of different percentages of hard dot screens. The standard is to use screens with 54 or 60 dots per cm. As for the percentages, a specific range of steps is chosen, as e.g. 6, 16, 25, 34, 44, 55, 70 and 100 %. In the standard four colour process yellow dots are placed vertically and horizontally (0°), magenta under 15°, black 45° and cyan under 75°. In DIN no.16547 published in 1983 a deviation of not more than ± 0,05° is specified for these angles. If this tolerance is not observed a coarse pattern, the so-called Moiré-effect appears, when two screens are overprinted. Schmidt (1975) has found that variable intervals give better results than these standard angles.

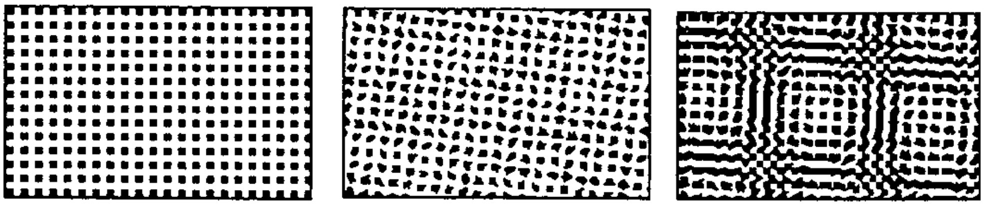

Figure 13: Moiré-effect with an overprint of two screens and an angular difference of 7°.

6.3 Rational screen angles in digital image processing

In contrast to conventional screening, screens produced on a rasterplotter can be formed only within the discrete grid cells with clusters of pixels of the size of the grid resolution. If such a pixel is 25mm and if we use a screen cell (bitmap) of 7 x 7 pixels, we obtain an interval of 57,1 dots per cm. If the same cell is to be repeated at regular intervals with other angles, there is a limited number of possibilities (see table 3), each of them having a different interval. The IfAG has developed such a set of rational screen angles (rows indicated in bold letters in table 3) that matches approximately the combination of intervals and angles found by Schmid (1975).

vertical steps	horizontal steps	screen angle in °	interval dots per cm
0	5	0,0	64,0
1	**5**	**11,3**	**62,8**
3	**5**	**31,0**	**54,9**
3	4	36,9	64,0
4	**4**	**45,0**	**56,6**
4	3	53,1	64,0
5	3	59,0	54,9
5	2	68,2	59,4
5	**1**	**78,7**	**62,8**
5	0	90,0	64,0

Table 3: Rational screen angles with a 5 x 5 bit map; the four rows with bold letters approximate Schmidt's solution.

In the sample above the form of the dots is always the same. In other cases it may vary. Several attempts with different bit map sizes and certain tricks have been made to approach the angle

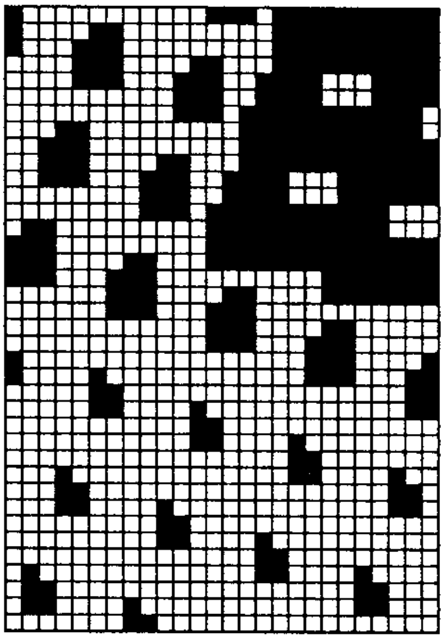

Figure 14: 6x6 bit map, 18°, 14, 31, 83 %.

differences needed. So e.g. the "High Quality Screening" system by Linotype-Hell is based on the principle that only every third screen dot defines the correct angle. The others in between are shifted by less than one resolution unit. 3 x 3 cells form together a supercell.

6.4 Irrational screen angles in digital image processing

Highend rasterplotters may use irrational screening, whereby each dot is calculated individually (fig.15). The conventional screen angles may be used. Dots in irrational screening are arranged around the centre of the cell and formed as compact as possible. This is necessary to control the dot size in printing. Screen values may increase by taking too much ink the longer the outline of the screen complex is. In order to avoid a sudden increase of tone, when the dots begin to touch each other (arround 50 %), elliptical dots may be calculated. With some minor modifications raster plotter technology allows also for line screens. Screens in which the dots are distributed regularily are called amplitude modulated (figures 15 and 16). Different tones are the result of different dot sizes. The number of tonal values that may be obtained depends on the resolution. A 60 dots per cm or 150 dpi screen cell together with 25mm resolution results in 40 pixels per cell, each of them giving an increase of 2,5 %.

6.5 Frequency modulated screens

Different tones, however, may be achieved also by a different number of dots per area unit. These screens with random distributed dots of equal size are called frequency modulated (fig.16). One of the advantages of fequency modulated screening is that a fairly large dot may be used throughout the image, e.g. 600 dots per inch instead of 2000, what allows for a cheaper plotter.

6.6 Plotting continuous-tone files in continuous-tone mode

So far only flat tones have been considered. But orthophotos and hill shading originals have a continuous-tone structure. If they are stored digitally, they must be broken down in a number of

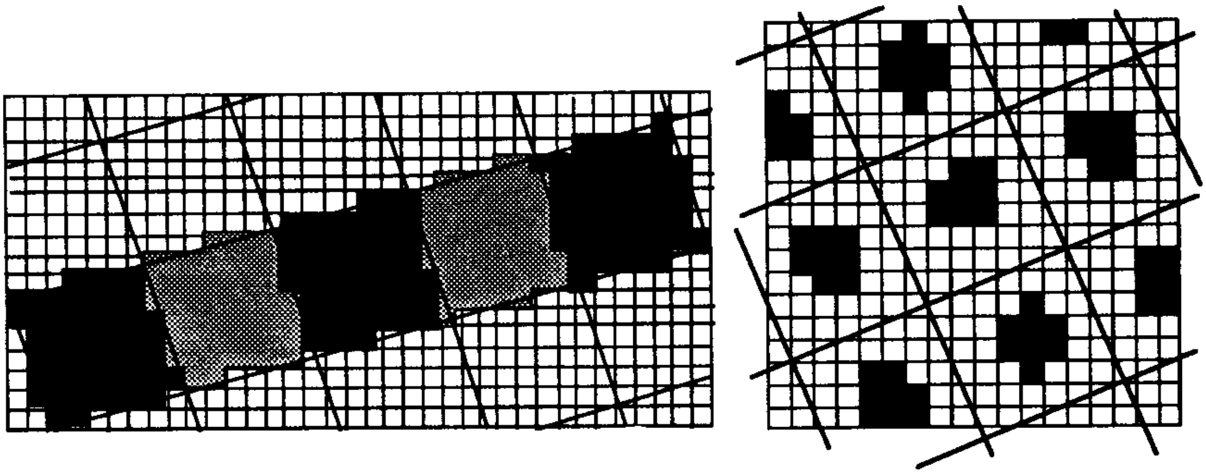

Figure 15: Irrational screen angle for cyan (75°); 100 % equal approximately 55 pixels, each dot has a different form.

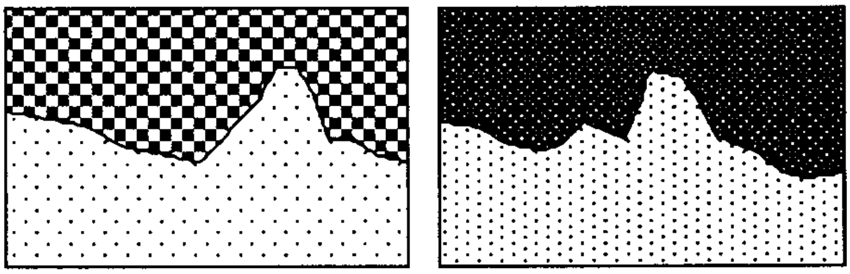

Figure 16: Amplitude modulated screen type with fixed interval (left) and frequency modulated screen type with variable interval (right).

discrete steps. A grey scale of 256 steps can be rendered with 8 bits per resolution unit. Some plotters allow for a "continuous-tone plot", better to say allow to plot these 256 grey tones on photographic paper or film.

6.7 Plotting screened continuous-tone files

For the production of a large number of copies of continuous-tone images on an offset press, these images however must be screened. Fig.17 illustrates the general principle of determining the dot size within each cell of in amplitude modulated screening.

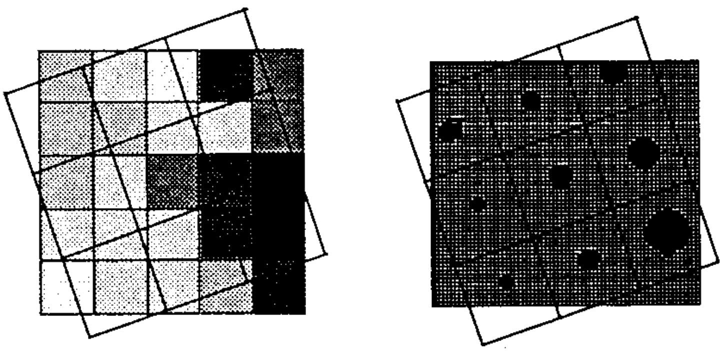

Figure 17: Continuous-tone file (left), screened for cyan at 75° (right).

Continuous-tone files may be rendered also by frequency modulated screens.The dots being random distributed, there are no more Moiré-problems. There are two common methods to caluculate the

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dot distribution. Better images can be achieved with two-dimensional the error-diffusion method. In a first step a screen dot (of uniform size) is set or not set for each image element depending on a mean threshold, what results in gross errors, especially in the medium tones. These errors are distributed in the neighbourhood of the first dot. The disadvantage of this method lies in the fact that computing such an image take a lot of time. The other method is called dithering, whereby the threshold is replaced by a periodial sequence of tones in a threshold matrix of e.g. 8 x 8 pixels.

6.8 Improving details by edge enhancement

If an orthophoto contains fine details they usually suffer from amplitude modulated screening. They may be improved to some extent by the edge enhancement technique, by which dots are reduced in size on the light side of an edge and increased on the dark side. However, we have experimented with another method that increases contrast and enhances such edges even more. The technique is to enhance the cot-file and derive from this stage by thresholding a binary file with fine dark edges only. In plotting this binary file is added to the screened image. Such an improvement of detail may be achieved also by frequency modulated screening.

6.9 Plotting resolution

The question is, what plotting resolution does one need for high quality raster plots, all types of map elements included. The general tendency is to allow for a minimum pixel size of 0,025 mm, which corresponds to 400 dots per cm or 1000 dpi. A fine contour line of 0,1 mm is only 4 pixels wide at this plot resolution. This may cause some irregularities in line widths in the order of 0, 02 mm which is already noticeable. Small letter sizes of 1,2 mm have a stem of 0,12 mm, but may have hairlines 3 times smaller, what leaves only one or two pixels for this part of the letter. We have indicated above that in screening flat areas a plot resolutzion of 0,025 mm allows for a range of tones with steps of 2,5 % only.
Therefore we may accept a plot resolution of 1000 dpi, but recommend 2000 dpi or 800 dots per cm for plotting colour separation films of multicoloured maps, including orthophoto maps.

7. CONCLUSIONS

In this contribution we covered the critical path for the production of high quality cartographic output starting from photogrammetric data and ending with processing on the raster plotter colour separated films ready for printing on an offset press. The amount of editing on the original data is often largely underestimated. Various refinement procedures are usually unavoidable, if a graphically sound map image is envisaged. Whenever major scale changes are involved, generalization procedures will be needed as well. Both functionalities, vector and raster editing, have their advantages and should be available on a cartographic workstation, often used in a foreground/background mode on the display.
The rasterization procedure for vector data is an important element in the whole process. The same is true for the screening technology. Recent developments in digital screening have finally reached the quality standards of traditional reprographic techniques, so that entirely digital map production has by now become reality. They even offer a number of advantages over conventional procedures. A fairly good insight and know-how on various aspects of the screening techniques is necessary in order to produce Moiré-free overprints and orthophotos with enough details. For the sake of the map user a raster plotter resolution of better than 1000 dpi should be chosen.

8. REFERENCES

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