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Semi-Automatic Mapping Techniques

A procedure is envisioned which includes stereoplotting, digital computing, and orthophoto printing in off-line and separated facilities.

Abstract: *A semi-automatic orthophotomap compilation technique is considered, consisting of a metric determination of the terrain relief (e.g., by manual plotting contour lines with topographic plotters) and an automatic, computer controlled, orthophoto printing. The procedure can be fast, flexible and accurate. It may also be convenient for management of the work. Metric information of the terrain relief can be converted by an electronic digital computer into signals suitable for the control of the orthophoto printing. Signals to be provided yield corrections, due to the relief- and tilt-displacements, for differential scaling, and for correcting the local image distortions caused by the terrain slopes and the geometry of the photograph. Corrective signals can also be generated for the curvatures of the terrain forms. In addition the computer may provide signals for some cartographic editing of the orthophotographs during the printing stage. For automatic orthophoto printing, different equipment and techniques are applicable. The equipment may range between simple direct optical projection printers and sophisticated optical-electronic printers. The techniques can be based on printing by narrow parallel bands, zonal printing, or printing of facets. The last mentioned possibility can be extended from the tilted terrain surfaces (facets) to the second- or higher-order surfaces.*

Introduction

The present day availability of electronic, digital computers facilitates and stimulates the development of more efficient map-making techniques. A map compilation process may be divided into phased processes which are separated in time and space. The metric data of the relief of the terrain to be mapped can be established in the first phase, then converted into appropriate signals for the ortho-projection in the second phase, whereas in the third phase, the orthophoto printing process is accomplished. The contour lines, together with some annotation, can be printed on the orthophotographs in the later reproduction stage.

At present, efforts are being made by various institutions and organizations to process the drop-line data being obtained by profiling of the terrain models, through the use of digital computers in order to automate the production and possibly improve upon the accuracy of the contour lines. For this purpose proper interpolation techniques have to be used. There is, however, a certain accuracy limitation for contour lines derived in this way; it is imposed by the topographic characteristics of the terrain.

The essence of this paper is to outline a map-making technique that provides accurate contour lines and orthophotographs of good quality, although no attempt will be made on the part of the author to elaborate on the techniques in detail here. In addition, an attempt is made to achieve the most favorable assignment of work functions to the systems' manually and automatically operated components. This proposed orthophoto technique offers a means of remapping or map revision of areas where the geometry of the relief has been already determined, recorded and stored.

A semi-automatic technique appears to be feasible if:

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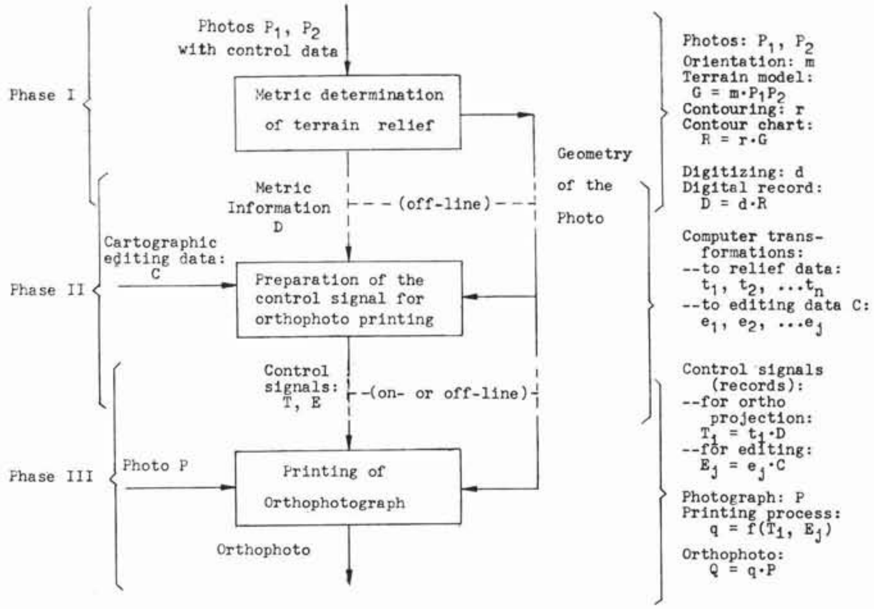

FIG. 1. The three basic phases of the process and the corresponding inputs and outputs.

- The automatic restitution of the relief, e.g., by means of drop-lines, gray shades or the derived contour lines, does not meet the specified performance standards or
- If the geometry of the relief has been pre-determined.

The first case concerns *large scale mapping* by means of correlators and associated control units where performance is lowered, e.g., by the vegetation and obstacles on the terrain. It may also apply to *medium* and *small scale mapping* where accurate geomorphologic representation is demanded. The second case concerns areas to be remapped, either where existing maps have to be revised, or where the relief has been predetermined, e.g., by contour lines, spot heights or other techniques such as relief determination from shades on the lunar surface.

The restitution process resolved in the three basic phases has the following potentials:

- High *flexibility* for the management of the production process,
- *Versatility* regarding the restitution techniques,
- Capability for improved *performance*.

The orthophoto techniques are expedient where the quantity of the semantic information to be represented is in great detail, or in areas lacking in particular detail (e.g., deserts, forests, etc.), thus wherever photographic presentation is preferred to line representation.

PRINCIPLE

The proposed semi-automatic technique is characterized by the definition of the geometry of the terrain relief so that the specifications on accuracy and geomorphologic fidelity will be met, and by the subsequent generation of signals for the control of the orthophoto printing. The geometry of the terrain's relief, derived in the first phase, is generally not presented in a form suitable for the control of the printing process. Therefore, it must be converted into appropriate control signals. Figure 1 shows the three basic phases of the process and the corresponding inputs and outputs.

The *first phase* concerns the acquisition of the metric information of the terrain relief. The most frequent case will be the compilation of *contour lines* by conventional stereoplotters. The contour lines can be scribed or plotted and may be simultaneously digitized and recorded on a magnetic tape or disc.

As the metric information of the terrain relief is provided by the conventional plotting technique, it will be sufficiently accurate, and the geomorphologic representation satisfactory. Direct compilation of the contour charts is in general faster and more accurate than indirect compilation from the drop-line charts. For flat terrain, locations (X, Y, H) of the characteristic terrain points or of a point-grid can be measured and recorded. The contour lines may be automatically interpolated at a later stage.

If maps with sufficiently accurate relief presentation are available, the contour lines can be digitized, e.g., by means of a pencil follower, and fed to the computer for the derivation of the control signals. The contour lines may also be used directly for a manual preparation of the control signals (Phase II). Apart from the above, other techniques and sources (e.g., digital models, shadows, etc.) can be used for the metric determination of the terrain relief. The subsequent generation of the control signals must be adapted to these techniques.

The *second phase* concerns the conversion of the metric information provided by the first phase into signals (records) for the automatic control of the orthophoto printing (Phase III). The corresponding transformations can be separated in time and space from the first phase. For their accomplishment different means can be used ranging from simple devices operated manually (Drobyshev, F. V. (1968)) to the electronic *digital computers*. The latter are preferable as the transformation can be fully automated and performed at a high speed. If the metric information is presented in form of scribed or plotted contour lines, these can be digitized automatically in this second phase and stored in the computer. The computer can also be used for manipulation of additional information for the cartographic editing of orthophotographs. For instance the cartographic grid and the projection can be considered. However, the computer programs have to be adapted to the type of orthophoto printer to be controlled.

Most of the present *orthophoto printers* are unable to exploit fully the potentials of digital computers for the control of the printing process. Consequently it seems useful to reconsider the design of the orthophoto equipment in view of their adaptation to the computer controlled off- or on-line operation (Phase III).

System components

Normally the basic system components will be:

* Simple *classical stereoplotters*, preferably with scribing facilities and/or the possibility for continuous digital recording of the contour lines, and provided with measuring devices for the orientation data;
* A *digital computer* provided eventually with a peripheral unit for automatic scanning and digitizing of the contour line plots (drawn or scribed sheets), and with the usual input and output facilities, and
* The *orthophoto printers* with the corresponding control units.

STEREOPLOTTERS

Contour lines can be compiled on comparatively simple and less expensive topographic plotters, providing a high production and satisfactory accuracy. However, measuring facilities are required for the orientation parameters, which are needed for the computerized conversion (Phase II) and/or for the setting up of the orthophoto printer (Phase III). The measuring devices for the relevant orientation parameters should be calibrated and adjusted.

If the computer is provided with an automatic scanner-digitizer, the most appropriate output of the stereoplotter will be scribed contour lines. They are convenient for automatic digitization and may be used directly in the final cartographic reproduction stage. Another possibility is to digitize and record the contour lines directly from the plotter and to plot them as a by-product at a desired scale.

In nearly flat terrain models it is possible to measure and record the locations of the characteristic model points or, better, a homogeneous grid of points. The contour lines can then be interpolated by the computer during the second phase.

COMPUTER

The conversion and manipulations of the metric information for the orthophoto printing can be realized, if using appropriate programs, by means of a less-powerful electronic digital computer. The requirements for speed and accuracy of the data processing are not high. The inputs may be metric data on the terrain relief in digital form, data on geometry of photographs (e.g., tilts), scale desired for the orthophotographs, some data and instructions for cartographic editing and the programs for the conversion and manipulations.

The computer can operate with the orthophoto printers on-line or off-line. In the second instance, tapes have to be produced for control of the time-delayed printing. These tapes carry the recorded control signals for height tracking, for the optical units, or for the electronic scan of the orthophoto printer. These control signals must be adapted to the mode of operation of the orthophoto-printer.

The modes of operation are: printing of narrow parallel bands, printing of equidistant height zones, printing of facets.

In the profiling mode of printing by continuous *narrow parallel bands* or by discrete *small area elements* (image increments), the

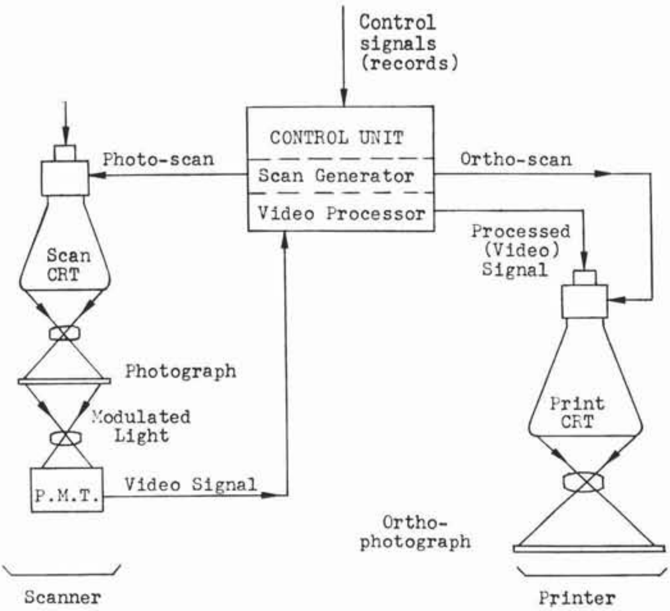

FIG. 2. If optical-electronic printers are used, signals which will correct the image distortions due to terrain curvatures may also be provided.

corresponding control signals concern corrections for the relief and tilt displacements, and for the differential scaling of images. The computer may provide additional control signals for the correction of image distortions due to terrain slopes and geometry (inner orientation and tilts) of the photograph, and even signals for the cartographic projection. If optical-electronic printers are employed (Figure 2), signals which will correct the image distortions due to terrain curvatures may also be provided. These corrections can be approximated by the second- or higher-order polynomials.

An alternative approach to the compilation of orthophotographs is to print *zones* limited by adjacent contour lines. In using an optical-electronic printer, the digital computer should provide control signals for the scanning of each individual height zone, and for adapting the scan to the local terrain slopes and curvatures. The zonal screening and the scan adaptation can be controlled by the digital technique.

Another possibility is the method of *partial printing of facets*. The facets, representing plane surfaces with different tilts, form an irregular polyhedron which approximates the terrain relief. For an optical-electronic printer, control signals may be provided for screening of the individual facets and for scan adaptation to the slopes. The method can be extended to arbitrary curved terrain shapes to which the scan can be adapted approximately by second- or higher-polynomials.

Control signals can also be prepared for some cartographic editing during the orthophoto printing stage. For instance, several orthophotographs and/or parts of them can be printed on a desired format, and a cartographic grid or tick marks and contour lines may be over-printed. The use of digital computers for the preparation of control (and editing) signals provides a great flexibility, high speed and a good accuracy. In on-line operation one computer can simultaneously control the operation of several orthophoto printers on a time-sharing basis.

ORTHOPHOTO PRINTERS

The control signals prepared must be adapted to the constructional and operational properties of the printing equipment. With *direct optical projection printers* [e.g., B. & L. Orthophotoscope (Scher M.B. (1964), G-Z Orthoprojector (Ahrend M. and others (1964))] only the signal for height control needs to be provided for the printing process.

In *optical printers* having a *separate optical train* and perpendicular projection [e.g., OMI Orthoprinter (Astori B. Parenti G., 1967)], additional signals are desirable for differential scaling and the corrections of image distortions due to terrain slopes and geometry of photographs. These signals control the rotations of a Dove (or equivalent) prism, and the displacement of lenses of a variable magnification (e.g., panchratic or zoom) system. The potentials of the electronic digital computers for preparation of control signals can be fully exploited by the optical-electronic scanning printers. The printing process can be performed by narrow parallel bands, by small area increments, by partial printing of inclined planes (facets) or curved surfaces, and by zonal printing. Figure 2 shows the principle of an optical-electronic scanner-printer. In the off-line operation of the computer and printer, the input for the control unit is the records (e.g., tapes) of the control signals as prepared by the computer. The control unit is provided with scan generators for the scanning and printing cathode ray tubes (CRT); hence, it controls the voltages applied to the deflection coils of both CRT. The rasters on the faces of the two tubes differ in location for the relief and tilt displacements and in size due to the difference in scale. Their shapes are also different because of the effect of the terrain slope and of the geometry of the photograph. The video signal, generated by the photomultiplier (PMT), can be processed by the video processor, which is attached to the control unit. The processing may apply to screening of zones (or facets) by means of the relevant control signals, filtering of undesired frequencies, dodging and the inversion of the video signal.

If the faces of the CRT are sufficiently large to cover the whole photo- and orthophoto-planes, the problem of inertia associated with mechanical tracking is eliminated. Consequently, the printing process can be performed at a high speed. However, as the scanning raster is in practice not fine enough to provide the required image quality for printing, this advantage is diminished.

If the faces of the CRT are smaller, printing can be accomplished in successive sections. After printing of each section the photo- and orthophoto-planes are simultaneously displaced mechanically (e.g. by means of servo motors) to the center of the next section. The sections may be defined by the lines of a cartographic grid, so facilitating the direct compilation of map sheets. In printing by sections, the scanning rasters can be fine enough to provide good image quality. However, the mechanical components of the equipment are more complicated than in the former case due to stepped tracking between sections.

In on-line operation of a digital computer with an orthophoto printer, the control unit of the printer can be considerably simplified. Some digitizers, and also recording and reading units, can be omitted. Additional information can be printed on orthophotographs by the replacement of the video signal with a constant current on the cathode of the printing tube. The voltages on the coils for deflecting the electron beam should be controlled according to the information to be printed. The orthophoto printers discussed to illustrate the obvious potential and versatility of semi-automatic techniques.

In the following, some consideration will be given to the management of a mapping technique consisting of manual contour-line plotting, automatic transformation by means of a digital computer and automatic orthophotoprinting.

MANAGEMENT ASPECT

The technique under discussion is particularly convenient for use by governmental and other organizations which are required to produce large numbers of new maps or to revise the existing ones. The process, broken down into basic phases (as indicated earlier), can be performed in a decentralized manner at different places and at different times. The restitution system may consist of several (n) stereoplotters, a digital computer, and of several (m) orthophoto printers (Figure 3). The three basic components can be located arbitrarily. The computer may belong to another department or organization—it is sufficient to have access to it.

Accomplishing the process in phase facilitates decentralized execution and also employment of the personnel trained only for one work phase. The most time-consuming phase is expected to be the manual compilation of contour plots, whereas the computer

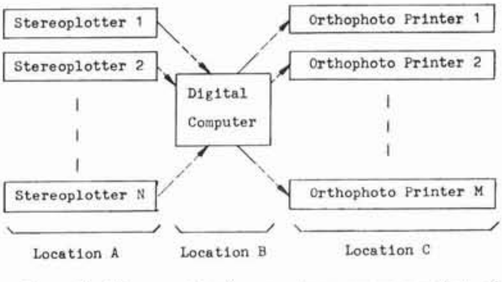

FIG. 3. The restitution system may consist of several stereoplotters, a digital computer, and several orthophoto printers placed in separate locations.

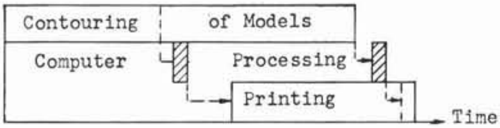

FIG. 4. Time schedule for the three working phases: contouring, digital process, and orthophoto printing.

processing can be very rapid. The printing rate varies with the type of relief, the size of the orthophotographs and the dynamic characteristics of the orthophoto printer. Figure 4 shows a time schedule for the three working phases—contouring, digital processing and orthophoto printing.

The short time delays between the phases arise from the transfer of data and materials from one phase to the other. The computer processing can be realized, e.g., in two (or more) parts for groups of models together, provided that the time gap between the end of the contouring and the end of the orthophoto printing is brief.

Conclusion

Acquisition of the metric information on the terrain relief (e.g., plotting of contour lines) is supposed to be independent of, and realized before, the orthophoto printing. The computer-controlled off-line or on-line printing process facilitates great flexibility, fast operation and adequate accuracy. Different methods of representation of the relief and different geometries of the photographs can be adapted. Even some cartographic editing can be included in the orthophoto printing process. The technique is particularly convenient for mapping of areas where the geometry of the relief has been already determined. It is applicable also to other celestial bodies. The equipment and methods may differ considerably, ranging from simple direct optical projection printers operating in narrow parallel bands, to optical-electronic printers operating, e.g., by zones, facets or curved surfaces.

The signals for the printing control should preferably be prepared in a digital computer. These signals may provide the locational corrections for the relief and photo-tilt, for the differential scales, and for image distortions due to the terrain slope and geometry of photographs. If printing is done with optical-electronic printers, operation in constant-height zones or by facets seem to be particularly convenient, as a digital screening technique can be employed. The zonal printing and printing of facets could be performed very rapidly.

A time delay between the metric acquizition (e.g., compilation of contour lines), the preparation of the control signals by an electronic computer, and the printing stage is desirable also from the management point of view. The three phases can be separated in time and executed to a great extent decentralized.

If desired, one computer can operate on-line with several orthophoto printers. Hence, some of the digitizers and automatic recording and reading units are omitted. Manual compilation of contour line plots, e.g., by means of simple topographic plotters, their digitization and conversion into the desired control signals with an electronic digital computer, and the automatic printing of orthophotographs with specially designed printers, represents a rational approach to the problem at present. The representation of the terrain relief by directly plotted contour lines is accurate, geomorphologic fidelity is high, and production is good. The generation of signals for controlling the printing can be automated without introducing the deficiencies of the automatic correlators. Hence, the printing can be performed by less expensive and more reliable equipment. The contour lines, plotted in the first phase, can be printed on the orthophotographs in the reproduction stage.

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