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RECENT TRENDS IN THE DEVELOPMENT OF
AUTOMATED PHOTOGRAMMETRIC INSTRUMENTS

1. ABSTRACT

For three decades, the development of automated photogrammetric instruments has evolved from modification of conventional instruments or computer controlled plotters to the fully automated instruments of today. The latest category is characterised by the presence of image correlators. Recent trends in the development of automated photogrammetric instruments are discussed with special emphasis on the process of scanning and digitizing of aerial imagery and the digital sensing of image parallax (electronic correlation). Various systems for the production of orthophotos, stereomates and digital elevation models (on-line or off-line) are acknowledged. The modification of conventional photogrammetric plotters with devices for recording of digital map data and their interface with peripheral components for interactive editing are given.

2. INTRODUCTION

Concerning instrumentation, the development of new equipment during the last few years was rather limited. The emphasis was on developing new application by optimizing available instruments and extending their capabilities by means of attachments and other peripherals, mainly digital. Several experimental systems were developed into production systems and others disappeared, at least for the time being.

When considering recent trends in the development of automated photogrammetric instruments the definition of "automation" becomes inevitable. It is often used synonymously to indicate the replacement of a human operator. Automation is also used to indicate that some aspects of the operation performed is sensed and that the obtained information is used to control the further progress of the operation. In brief, automation can be defined as the automatic control of the operation of a system, process or apparatus by devices that reduce the human effort and/or decision.

When considering automated photogrammetric instruments we will consider the automation of topographic and planimetric detail compilation. Several systems are available for the automatic compilation of topo-

graphic detail in the form of digital elevation models and contours. Since planimetric compilation requires a solution to the pattern-recognition problem, automatic planimetric compilation is feasible only with the acceptance of orthophoto as a map product. At present, numerous systems for automated orthophoto production are available.

Due to the increased emphasis on digital map compilation by direct digitization from stereoplotting instruments, the development of interactive map compilation systems with distributive computer networks is reviewed.

3. FULLY AUTOMATED PHOTOGRAMMETRIC INSTRUMENTS

The automation of stereo photogrammetric instruments requires a means for the rapid and accurate sensing of parallax between stereo images. This is generally achieved by the automatic scanning and matching (correlating) of conjugate imagery.

At present, different techniques may be used for the scanning of the stereopair. These include: electronic scanners (cathode ray tube devices, vidicon type devices, or image dissector tubes); solid-state scanners (self-scanned photodiode devices, charge-coupled devices, charge injection devices or charge-coupled photodiode devices) and electro-optical scanners (lasers, light-emitting diodes or conventional lamps). The matching of the scanned imagery is done by electronic correlation, digital correlation or coherent optical correlation. In the following discussion, a review will be given to existing scanning systems and the methods employed for the correlation of conjugate imagery.

3.1 Electronic Scanning Using CRT's

CRT scanning is the most widely used system for scanning the stereo diapositives. The basic components of the system are a pair of flying spot scanners, fixed optics (objective and field lenses), photomultipliers and raster shaping control modules (x and y deflection system).

The left and right diapositive carriers are positioned in the scanner modules by the system computer so that the homologous areas are scanned simultaneously. The flying spot of light of the CRT (the raster) is imaged by the objective lens in the plane of the diapositive. The light transmitted through the diapositive is collected by the field lens and is converted to a video signal by the photomultiplier. After scale and rotation correction have been made to the scanning pattern, the two areas are identical except for parallax due to height. To the correlator the parallax appears as a phase shift between the video signals.

At present, several automated photogrammetric systems with CRT scanning are available. For example, the Gestalt Photo Mapper (GPM), the Universal Automatic Map Compilation Equipment (UNAMACE), the Topomat system and the Itek system. The area scanned varies from 0.25 x 0.50 mm in the UNAMACE to a 9 x 8 mm patch in the GPM.

3.1.1 Correlation of Video Signals

The processing of video signals produced by electronic CRT scanning devices is normally achieved in an electronic correlator. Despite the similarity between the existing systems, they will be discussed separately.

In the GPM system, the video signals from each scanner are filtered into six frequency channels, each of which responds to different rates of change in the magnitude of the video signal. The process is similar to Fourier analysis in that the signal is analyzed into harmonic frequency terms each of which is assigned a coefficient equal to the number of video level changes detected by the channel of corresponding frequency.

Separate parallax measurements are made for each of the six channels by cross-correlating the digital coefficients generated by the video-to-digital converter. Nearly 80,000 binary cross-correlating products are calculated for every scan of both patches. The signed magnitude of these products is proportional to the phase separation of similar video patterns from the two diapositives and are summed to form 2444 12-bit numbers, each of which represents the parallax detected for homologous areas on the left and right diapositives.

In the UNAMACE, the video signals from the CRT scanners are fed into a height-error sensor consisting of two delay units and two correlators. The displaced correlation functions are appropriately summed to provide net height-error signals. These signals are passed to a displacement-error measuring unit consisting of an integrator, a positive and negative threshold detector, a reversible counter and digital-to-analog converter. If the integrated error signal exceeds one of the threshold limits, the detector steps the reversible counter in a corresponding direction and resets the integrator to zero. The counter operates a D/A converter that produces a voltage to deflect the center of one of the diapositive scans in a direction to reduce the observed time differential. This operation continues until the height-error has been compensated.

In the Itek correlator, the video signals are channeled to the correlator through video amplifiers, where they are split into several frequency bands to allow the low spatial frequencies to be correlated first, progressing to higher frequencies as the accuracy of alignment is improved. A channel selector is used to select the optimum channel depending on the degree of correlation. The output is analyzed and is passed to the integrators. The first order signals from the integrator are applied to a scanning pattern modulator to cause appropriate transformation to the scanning raster waveform. The modified scanning waveforms are added algebraically in the sum and difference circuit to provide equal but opposite transformation to the left and right rasters.

In the Topomat, the correlator processes the video signals after signal shaping by three band-pass filters with different transmission bands. A delay line, whose delay time is adjusted to the cutoff frequencies, is associated with each band-pass filter. Using cross-correlation technique a discriminator characteristic is produced, which permits correlation between parallax polarity and voltage polarity. An integra-

tor is used for the transition from digital information at the output of the correlator to analog control signals for the z motor.

3.2 Solid-State Scanners

If an image is projected onto a sensing array device, the system is capable of detecting the position (x and y coordinates) and as a third coordinate the light flux incident on the matrix elements. Grey values can already be digitized in more than 16 grades.

Solid-state devices consisting of photodiode arrays in a linear or matrix form were used in remote sensing (Thompson 1973) as sensors of satellite camera systems and in measuring detectors (O'Conner 1972).

In automated photogrammetric instruments, solid-state scanners by means of self-scanned photodiode arrays are used in the Rastar system (Hobrough 1978). The Rastar system was reported as an experimental system and uses a linear array consisting of 1728 elements. The photo images are enlarged slightly to give 10 micrometer diode spacing at photo scale. The arrays are rotated by servo motors so as to lie substantially along epipolar lines on each photo.

The basic components of the Rastar are the video processors, transformation delay modules, loop processor and output processor. The correlation of the analog video signals from the self-scanned photodiode array is based on cross-correlation techniques (Hobrough 1978).

3.3 Electro-Optical Scanners

Image scanning is performed by mechanically deflecting a Laser light across the left and right diapositives. The stage is mechanically moved with respect to the scanner to scan in the perpendicular direction. Mechanical scan deflection permits a very bright light spot to be used, which provides a higher scanner output signal-to-noise ratio. The spot brightness is limited only by the detector or by heating of the film.

Image density is scanned and measured on each photograph along epipolar paths across many profile lines parallel to the direction of mechanical carriage motion to obtain information on many parallel profiles or parallel lines of grid points.

The AS-11B-X system developed by Bendix uses this technique for scanning. A total of 1280 data points are collected along a swath by scanning along successive epipolar lines across the swath. The 1280 data points are sampled along the epipolar lines at a spacing of 20 micrometers. The epipolar lines are spaced 50 micrometers apart.

The AS-11B-X uses a digital correlator consisting of analog-to-digital converters, a buffer memory, an address modifications logic, a parallel processor and two minicomputers. The correlation is performed digitally by multiple-bit multiplication of corresponding image element densities. The image element density products are added over desired image areas, producing data integration over these areas. The digital correlator computes the amount of shift or parallax between corresponding segments

of imagery on the two photographs. The computation of elevation in an epipolar coordinate system is performed on-line. Further computations for the digital elevation model in the ground coordinate system is done off-line.

3.4 Digital Off-Line Correlation

An algorithm for image matching of digital stereo image densities was described by Panton (1978). The algorithm includes an image matching procedure in which parallax components are determined by automatically correlating corresponding images. The basic idea behind the matching method is to define a regularly spaced grid of points on one image and to find its conjugate point on the other image. The algorithm is implemented on a distributive network of parallel digital processors. Currently the primary output of the system is digital elevation data.

3.5 Coherent Optical Correlator

Two concepts were conceived and developed in Bendix Research Laboratories. In particular, they are the image/image correlator and the image/matched-filter correlator. A comparison of the two correlators showed that the image/matched-filter is more suitable for image search problems and thus for terrain relief extraction (Krulikowski 1972).

The coherent optical image/matched-filter processor is essentially an optical frequency-plane correlator in which one stereophotograph is transformed into a matched filter for the other stereophotograph, the filter having the form of a Fourier-transform hologram. Processor operation is based on the concept that the matching of conjugate imagery can be reduced to a process of signal detection. As the input photograph is scanned, the correlator detects conjugate image points, and the spatial position of the output light signals are direct measures of the differential coordinates.

From the photogrammetric point of view, the optical image/matched-filter processor is a special-purpose instrument that represents a departure from traditional stereoplotter design concepts.

4. AUTOMATION OF ORTHOPHOTO PRODUCTION

4.1 Electronic Orthophoto Printing

Two methods are available for printing an orthophoto electronically: the "slit" method and the "patch" method. In the slit method the film is traversed continuously by an exposing slit having a length approximately equal to the correlation zone. The printing of the orthophoto is a continuous process using the height correction generated by the correlator. The continuous printing by the slit method is suitable with instruments having a small correlation zone, such as the UNAMACE and Topomat.

In the patch method the film is exposed in an array of patches. The size of the patch is less than the correlating zone and is normally dependent upon the variation of terrain relief. In the patch method all motion and computation ceases before each patch is printed. The GPM system employs the patch method.

4.2 Digital Orthophoto Production

A software system was described by Keating and Boston (1979) for the production of orthophotos from digital elevation models (DEM's) and aerial negatives by using a microdensitometer as input/output device. From the known model coordinates and camera orientation parameters, the x and y image coordinates of either photo in the stereopair are computed for each interpolated model point. The densitometer is then used to extract the film density at each image point corresponding to each model point. These film densities are rewritten by the densitometer in corrected orthographic positions onto orthophoto film at any convenient scale.

4.3 Digitally Controlled Optical Orthophoto Printing

The Wild Avioplan OR 1 system is a digitally controlled optical printing system. The system operates in an on-line mode or off-line mode. Optical printing of the orthophoto is made by exposing a film through a slit under control of the system's computer, which controls all the input and output operations, computes model-to-photo transformation and drives the servo system in real-time. The system requires digital elevation profiles, camera parameters, and orientation data. These profiles may be obtained from DEM's produced by automated systems, analytical plotters or by profiling the model on analogue photogrammetric plotters. Profiles could be obtained by interpolating digitized contours from existing maps. The OR 1 could be interfaced to a photogrammetric system for the direct acquisition of profile data.

4.4 Production of Stereo-Orthophotography

The stereo-orthophoto (stereomate) is similar to the orthophoto except that it is printed with specified parallax restored. In automated systems employing CRT printing, such as the GPM, the rectified raster has a specified parallax restored before printing. In systems using optical printing, such as the Wild OR 1 the profile data are preprocessed to compute a set of pseudo profiles with the desired base-height ratio.

The stereomate and orthophoto are normally generated from two successive photos. The orthophoto and stereomate produce a scaled model free from y-parallaxes which could be used for direct map compilation.

5. DIRECT DIGITIZATION ON STEREOPLOTTING INSTRUMENTS

Over the last few years there has been a gradual infiltration of digital technology within mapping for the direct digitization on stereoplotting instruments. The rationale for exploiting digital technology for

mapping systems is related to perceived benefits derived by the use of digital technology as well as the increased capability anticipated within a digital base framework. Specifically a digital base involves the replacement of map manuscripts by digital files. By so doing the user has access to map data in a machine processable form which, may be used for the generation of special types of maps and charts or for deriving other forms of terrain data (e.g. elevation profiles from digitized contours).

From the experience of the Topographical Survey Division, Surveys and Mapping Branch, Ottawa, Canada, the possible system configuration, hardware and software were described in detail in a previous publication (Allam 1979). The basic system components are: analog photogrammetric instrument (or analytical plotter), digitizing devices, interactive graphic display and editing terminal, microprocessor, digital computer and storing devices. Software for data collection transformation, interactive display and editing and for data purpose storage, retrieval and manipulation are also essential.

With regard to the method and extent of involvement of digital computers and peripheral units for direct digitization from stereoplotting instruments, several feasible system configuration can be drawn up. In principle they can be classified according to the number of stations (single or multiple), the capabilities for interactive display and editing, and the communication between the system components (uni-directional or bi-directional). The recent trend in the development of these systems is in the use of multiple stations with interactive display and editing terminals in a distributive computer network (Allam 1979).

The development of distributed systems has been a natural outgrowth of requirements to increase our computational abilities for faster and more efficient computing. A distributed system is usually characterised by a multiplicity of logical and physical elements which are interconnected to varying degrees via some communication mechanism. The essence of any distributed system is in the multiplicity of components, as well as specialised elements. Even though the individual components operate autonomously there is normally a unifying element, for example, the common data base. Individual system components are coupled in such a way as to provide some level of overall system integration.

6. CONCLUSIONS

The traditional domination of flying spot scanners in automated photogrammetric systems is gradually being replaced by using solid-state scanners in the form of self-scanned photodiodes, and electro-optical scanners in the form of lasers. This will open new vistas for other devices for scanning, such as charge coupled devices, charge coupled photodiode devices and light-emitting diodes.

Orthophoto printing is dominated by electronic CRT's or optically. The recent advances in light-emitting diodes will result in some changes in this area.

Off-line techniques using software and parallel processors for the correlation of previously scanned and recorded imagery will have an impact on the production of DEM's, orthophotos and stereomates.

In the next few years, significant developments will materialize in the field of feature extraction and pattern recognition by automatically generating and maintaining feature-signature data bases.

As far as digital stereo compilation is concerned, the present trend is in the development of multiple station systems in a distributive network with bi-directional communication between the system's components.

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