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DIGITIZATION OF PHOTOGRAMMETRIC IMAGES

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1. INTRODUCTION

Digital information from photographs is ever more in demand today. 'Digitization of photographs here means converting analog photographs into digital grey levels, i.e. not the acquisition or management of object coordinates and codes in digital form, but the resolution of pictures into elements (pixels) and the digital description of the grey levels. This is no longer an exclusive research problem but has gained practical photogrammetric significance in the measurement of point coordinates and the preparation of map bases.

Digital image information can be collected in many ways, e.g.

- direct digitization during the taking of small-scale images (SPOT, LANDSAT, MOMS /1/, MEOSS), rectification of the image data to various precision levels, and use as the base for small to medium-scale maps;

- direct digitization during close-range photography and real-time analysis of the image data /2/;

- digitization of photogrammetric pictures and rectification of the image data for use as the base of medium and large-scale maps (e.g. BÄHR et al. /3/, LOHMANN and LUHMANN /4/);

- sectional digitization of photographic stereo pairs and digital real-time correlation for obtaining the object topography (INDUSURF, TOPOSURF, see SCHEWE /5/);

- digitization of signalized points in photogrammetric blocks for determining the point cordinates (ROLLEI system, LUHMANN and WESTER-EBBINGHAUS /6/).

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This list shows that photographic pictures do play a role as the base material for digitization. Direct digitization during the taking process has the advantage that the grain and the non-linearity of photographic emulsions are eliminated, but is counterbalanced by the high geometric precision and the easy mathematical reconstruction of the picture geometry that is ensured by the simultaneous exposure of numerous "pixels" on the photographic emulsion.

Carl Zeiss here presents a new system for digitizing photogrammetric pictures.

2. THE DIGITIZING SYSTEM

The high-performance photo digitizing system presented here is being developed jointly by Carl Zeiss, Oberkochen, and Intergraph, Huntsville, Alabama. The system consists of a scanner module, a workstation computer and the digitizing software.

- Scanner Module

The scanner module is based on the design principles of the Zeiss Planicomp with only one photo stage being used for the scanner. The transparent photograph to be digitized is placed on the plane glass plate of the photo stage. The largest format that can be scanned is 260 mm x 260 mm. The photograph is illuminated from above and projected distortion-free onto a CCD line arranged below the photo stage. During an exposure period of 1 ms or less a linear picture segment is scanned that is 1 pixel wide and 2048 pixels long (at a pixel size of 7.5 microns x 7.5 microns).

The whole photograph or a segment thereof is digitized swath per swath. While digitizing a swath with a width of 2048 pixels, the photocarrier is moved continuously in a direction perpendicular to the CCD line. Then the photo stage is shifted one swath width for digitizing the next swath. The photo stage motions are controlled by a microprocessor as in the Zeiss P-Series Planicomp. Some technical aspects are described in detail in section 3.

- Workstation Computer

The workstation computer is an Intergraph INTERPRO 345.
The CPU is a 32-bit CLIPPER RISC processor with a processing rate of 5 MIPS.
It is complemented by a 355 MB disk drive and a GX graphics processor that drives the graphics terminal (1145 x 885 pixels).
The interfaces to the user, to further disk drives, and to networks such as ETHERNET are controlled by an INTEL 80386 microprocessor. The scanner module interface is a separate pixel data interface that directly accesses the main memory and is designed for data transfer rates of up to 2 Mpixels per second.

- Software

The basic digitizing software for the workstation computer was written by Intergraph in C language. The programs can be driven with menus with a mouse and the alphanumeric keyboard. The basic software package includes all of the programs required for defining the scanning area and the scanning direction, for digitizing the defined picture segment, for storing the picture data in the mass storage unit and for displaying the picture data on the screen. The basic software package also includes utility routines for adjusting and calibrating the instrument.

3. MISCELLANEOUS ASPECTS

- CCD Line

A CCD line is used as sensor to achieve a high radiometric precision. Linear CCD sensors have a better signal-to-noise ratio than CCD area sensors (at identical environmental conditions). The Fairchild CCD 145 linear sensor is currently being used. It has 2048 pixels spaced 13 microns. Onto this CCD line the photograph is exposed with a specially designed low-distortion lens with a high modulation transfer.

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The imaging scale has been chosen so that the pixel spacing is 7.5 micron referred to the photograph. Thus a line with a width of 15.36 mm can be digitized at a time. By continuously moving the photo stage perpendicular to the sensor direction a swath with a width of 15.36 mm and a random length of up to 260 mm can be digitized, with the line spacing of 7.5 micron being obtained by synchronizing the scanning pulses. The synchronizing pulses are derived from a linear encoder.

- Speed

The maximum photo stage speed when digitizing a picture swath is 16 mm per second. This makes 15 seconds for a 240 mm long strip. 16 strips have to be scanned in a 240 mm wide picture, which takes about 6 minutes (15µ) at the maximum speed. A requirement for high scanning speeds is adequate CCD sensor illumination to obtain a short integration time for scanning a line. A 100 W halogen lamp and a large-aperture condensor are used in the presented system. The saturation illumination of 0.27 $\mu J/cm^2$ of the CCD 145 sensor is achieved at an integration time of 0.2 ms already. 10 min für 7.5 µm-Abstand.
At 7.5 mm per second and 7.5-micron pixels the data rate is about 2 Mpixels per second.

The system offers two possibilities for reducing the data rates:

- Scanning at a lower speed

- Combining four 7.5-micron pixels into one 15-micron pixel or combining more 7.5-microns pixels into even larger pixels, e.g. for quick-look scans. In this case the scanning speed can be increased in order to digitize an aerial survey photograph with a size of 240 mm x 240 mm considerably faster.

- Color

The illumination system contains a filter carousel with 4 positions for digitizing not only with "white" light but also, for example, with blue, green and red light. In this way, color photographs can also be digitized by means of three consecutive scans.

- Scanning Area, Scanning Direction

The scanning area width is always an integer multiple of the swath width (15.36 mm with CCD 145). The scanning area length may be up to 260 mm. The scanning direction can be varied by ±5° so that the scanning direction can be set precisely parallel to the picture edges, for example, (or parallel to a defined direction) without having to align the photo precisely. This allows small existing analog orthophotos, for example, to be digitized and integrated in a raster data base organized by national coordinates directly (without resampling). The scanning direction can be specified by means of a program that scans the environment of reference points, displays the photo sections consecutively on the graphics terminal for precisely setting the points on the screen, and then computes the point coordinates.

- Geometric Precision

What does "geometric precision" mean in the context of a digitizing system? In the case of photogrammetric instruments, the calibrated precision is usually specified, i.e. the precision after the instrument cooordinates have been subjected to an affine transformation.

This also applies (restricted to a similarity transformation) to metric cameras. With the latter, the calibration result is the individual camera focal length and possibly a radial distortions table.

Most digitizing instruments that scan several pixels simultaneously use optical imaging characterized by a scale and distortion values. The scale and the distortion may differ from instrument to instrument.

Of a precision digitizer one expects

- that the residuals caused by distortion and scale variations are very small or very well known,

- that the scale differences in the X and Y directions are very small or very well known,

- that the angle between the X and Y directions is very precisely 90° or that the deviation from 90° is known very precisely,

- that the connections between consecutively digitized picture segments match very precisely.

Although it would be sufficient to know the deviations from the desired geometry very precisely, the design goal for this digitizing instrument is to keep these deviations very small, at least so small that the deviations within the area of about 1000 x 1000 pixel that can be displayed on a screen are less than one pixel.

The positioning precision of the photocarrier is better than 2 microns (standard deviation).
The angle positioning precision of the CCD line is such that at a distance of 7.7 mm from the optical axis (end of the CCD line image in the photo) the deviations remain less than 1 micron.

The lens has a distortion of less than 0.005 % so that the maximum error caused by the lens distortion is less than 1 micron (referred to the photo). This quality is also ensured for color separations because the lens is corrected apochromatically.

In the Y direction parallel to the CCD line, the imaging scale is determined by the lens adjustment. In the other direction (the swath direction), the scale can be matched to the Y direction scale by appropriately timing the scanning pulses. In every case the actual scale is measured during calibration and is allowed for both during swath-to-swath stepping and during later picture data processing.

- Radiometric Precision

Surely the demand for a very high geometric precision is justified in digitizing photogrammetric pictures, but which radiometric precision should be requested? Does one need 8 bits per pixel or will 6 bits or even 4 bits per pixel, i.e. 16 grey levels, be enough?

This problem must be considered from two aspects: How many grey levels are needed for photogrammetric picture scanning, and how many grey levels does a photogrammetric picture have?

The first question was answered by SHORTIS /7/, for example, for close-range photogrammetry to the extent that 32 to 64 grey levels are enough. This applies to the well-defined objects and markers of close-range photogrammetry which generally can also be illuminated optimally. Under the more unfavorable conditions of aerial photography it may happen that the brightness of different objects varies by a factor of 4 in different places of the photograph (density difference 0.6). If one specifies 6 bits (64 grey levels) for the darker objects, one must provide 8 bits for the brighter objects. Therefore it makes sense to demand 256 grey levels for digitizing photogrammetric pictures. (The number of grey levels can, of course, be reduced later by digital image processing, e.g. contrast balancing.)

The second question "How many grey levels does a photogrammetric picture have?" points to the SELVIN law: *The mean fluctuation of the measured density is proportional to the diameter of the diaphragm used for measuring the photographic density* (i.e. in the digitizing system case proportional to the pixel size). If one assumes the difference between the distinguishable grey levels equal to the mean fluctuation (standard deviation) of the density, one obtains that the number of distinguishable density levels is inversely proportional to the pixel size: The higher the geometric resolution, the lower the radiometric resolution of photographic pictures with the same granularity. HEMPENIUS and XUAN JIA-BIN /8/ have empirically investigated these relationships and concluded that for 25-micron pixels only up to 5 bits (32 grey levels) make sense. This applies to standard aerial film with granularity numbers of 20 to 40 (e.g. AGFA-GEVAERT PAN 200 PE, KODAK PLUS X 2402). However, there are aerial films with lower granularity numbers of 10 and less for which 15-micron pixels require 6 bits (64 grey levels). Such films (e.g. AGFA-GEVAERT PAN 50 PE, KODAK PANATOMIC X) are being used more and more for aerial surveying ever since metric cameras can be equipped with FMC /9/,/10/, and it may be assumed that film with even finer grain will eventually be used in photogrammetry.

The radiometric precision of the digitizing system described in this paper should not be limited by the digitizer but rather by the photographic emulsion. This is why the digitizing system was designed for 256 relevant grey levels. Internally, a resolution of 10 bits is even used for digitization. 8 bits per pixel are transferred to the host after correction for the individual deviations of the CCD elements and the residual illumination inhomogeneities. This does not mean that 8 bits per pixel have to be stored in the mass storage unit. Depending on the film type and the photographed object, it may make sense to use appropriate data compression methods like truncating the four least-significant bits and combining two 4-bit pixels in one byte /8/.

4. PROSPECTS

The instrument concept presented in this paper has been matched optimally to the requirements of picture digitization in photogrammetry. The digitizing system built according to this concept is therefore the first universally applicable **high-performance scanner for photographic pictures**. The digital data collected with it permit, for example, the following applications:

- Digital image processing (e.g. histogram manipulation, filtering, mosaicking several pictures with grey scale matching)
- Integrating digitized aerial photos into raster data bases
- Digital rectification (digital orthophotos)
- Direct conversion of small analog photos to digital orthophotos
- Detection and correlation of signalized points or natural features in photogrammetric blocks for determining the point coordinates (bundle triangulation)
- Digital correlation of imaged natural points for producing digital elevation models

- Digital classification of natural objects (with restrictions depending on the taking method, e.g. non-linear intensity response, differing viewing directions when using large angular fields)

The new digitizing system is to permit the use of these methods, which are all known per se, with normal aerial photographs and close-range photographs. Series produced systems will be available as of about the summer of 1990.

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ABSTRACT

Carl Zeiss presents a new instrument concept for digitizing photographs. This instrument is designed specifically for converting photogrammetric pictures into digital data. Special emphasis is placed on geometric and radiometric accuracy.

DIGITALISIERUNG PHOTOGRAMMETRISCHER BILDER

ZUSAMMENFASSUNG

Es wird ein neues Geräte-Konzept von Carl Zeiss zur Digitalisierung von Bildvorlagen vorgestellt. Dieses Gerät ist ganz speziell für die Umwandlung photogrammetrischen Bildmaterials in digitale Bilddaten konstruiert. Dabei wird auf geometrische und radiometrische Genauigkeit besonderer Wert gelegt.

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