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H. P. Bähr

University of Hannover, FRG

Analog Versus Digital Image Processing of Photogrammetric Imagery

Zusammenfassung

Digitale Bildverarbeitung im Gebiet klassischer Photogrammetrie kann von den Verfahren profitieren, welche für die Fernerkundung entwickelt worden sind und anwendungsreif vorliegen. Die Erhaltung der hohen Auflösung photographischer Bilder führt allerdings auf Datenmengen, die heute noch nicht wirtschaftlich digital verarbeitbar sind. An Beispielen aus dem Bereich der terrestrischen Photogrammetrie wird die Flexibilität digitaler Bildverarbeitung demonstriert.

Abstract

Digital image processing in the field of conventional photogrammetry may use operational methods, which have been developed for remote sensing. Restoration of photographic imagery's resolution however, affords large data sets, which cannot be handled economically on today's computer generation. The flexibility of digital image processing is demonstrated for applications of terrestrial photogrammetry.

Résumé

Le traitement numérique des images dans le domaine de la photogrammétrie classique profite des méthodes, développées pour la télédétection, que sont prêtes à appliquer.Cependant,la conservation de la résolution géometrique des clichés produit tant de dates digitales, que ne peuvent pas être traité economiquement par la génération actuelle des ordinateurs. La flexibilité du traitement numérique des images est montrée par l'application dans le champs de la photogrammétrie terrestre.

1. Introduction

Progress in photogrammetry happened in the past in the field of analytical processing. The development of large digital computers in the sixties provided the tool for rigorous transformation of image coordinates into object coordinates. In analytical photogrammetry, the image itself serves primarily as a - very effective - coordinate memory. This means, however, a limitation of the large potential of photographic imagery.

Photointerpretation has always used the "semantic" information content of the imagery rather than the geometric one. Development of remote sensing during the seventies, particularly development of digital scanners, led to original image information in digital form. Consequently, digital image processing methods were developed and applied to semantic information analysis from airborne and satelliteborne imagery. Here, the image is digitally processed at a whole, not only for specific coordinates as in analytical photogrammetry.

Digital image processing has not been invented by remote sensing. Theory and technology was developed by information theory, communication engineering and electronic engineering. Many disciplines have profound experience in digital image processing, without any relation to remote sensing +). The general flexibility of digital image processing makes it a tool even for applications in the field of classical photogrammetry. First results are available for rectification of cylindrical walls (BÄHR 1978) and digital orthophoto production (KONECNY 1979, SCHUHR 1980).

Today, digital processing of sampled conventional photogrammetric imagery cannot yet compete economically with analog procedures, like photographic rectification or digitally controlled orthophoto production (VOZIKIS 1979). The data rate, necessary to maintain the photographic resolution in the digital version, still is too large for been handled with the present generation of computers (see paragraph 2). There is, however, a permanent tendency towards declining computing costs, which will allow economical digital processing yet during this decade.

Main advantage of digital image processing compared to analog methods is the possibility of semantic image manipulation, like image enhancement and classification. Adequate software packages, developed for remote sensing applications, are available. Nevertheless, photographic image processing will ever play an important role in photogrammetry, but digital procedures extend the scale of powerful photogrammetric methods.

2. Sampling of Photographic Imagery and Display of Digital Data

For digital processing of data, which originally is collected in photographic form, digitization is necessary as a first step; finally display of the processed digital data in photographic form is necessary for evaluating the result, according to Fig. 1. Each step in Fig. 1 corresponds to a linear system, for which properties have been thoroughly investigated by system theory (see i. g. OPPENHEIM / SCHAFER 1975, PRATT 1978, LÜKE 1979). A photographic image represents a two-dimensional continuous signal

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+) ROSENFELD (1976) lists 410 papers which refer exclusively to digital image processing in c y t o l o g y which has to be sampled and quantified in order to allow discrete digital processing. For comparing analog and digital image processing, one has to answer the question

How has a photographic image to be sampled and how has digital data to be displayed photographically without any reduction of information (resolution)?

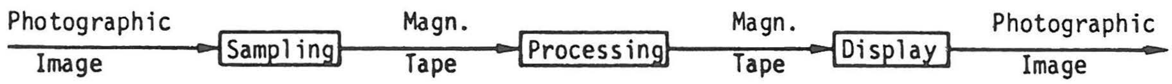

Fig.1: System Sequence for Digital Processing of Photographic Imagery

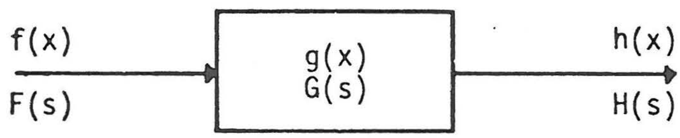

Fig.2: System Properties in Spatial and Frequency Domain

$$h(x) = f(x) * g(x) \qquad (1) \qquad\qquad H(s) = F(s) \; G(s) \qquad (2)$$

$$h(x) = \int_{-\infty}^{+\infty} f(\tau) \; g(x-\tau) \, d\tau \qquad (3) \qquad \mathcal{F}\{h(x)\} = H(s) = \int_{-\infty}^{+\infty} h(x) \, e^{-j2\pi sx} \, dx \qquad (4)$$

In system theory, signals are regarded both in the spatial and the frequency domain. Following Fig. 2, the input signal in the spatial domain is f (x) +), the impulse response g (x), and the output signal (result) h (x). In the frequency domain the parameters correspond to the input spectrum (F (s)), the frequency response (G (s)), and the output spectrum (H (s)). The resulting output may be computed by the convolution integral in the spatial domain (Equ. (1), (3)) and by simple multiplication in the frequency domain (2). H (s) and h (x) are linked by the FOURIER-transform (4). FOURIER-transforms of several important functions are known a priori, i. g. for the rectangular pulse (Fig. 3 a) and the Scha-function (Fig. 3 b).

Photographic imagery represent band limited functions. According to Fig. 4 this means, that a frequency limit exist at $s = \nu$. Sampling of the corresponding spatial function f (x) can be analytically expressed by multiplying a Scha-function (Fig. 5). If the phase of the Scha-function is

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+) in favour of simple notation limited to one dimension

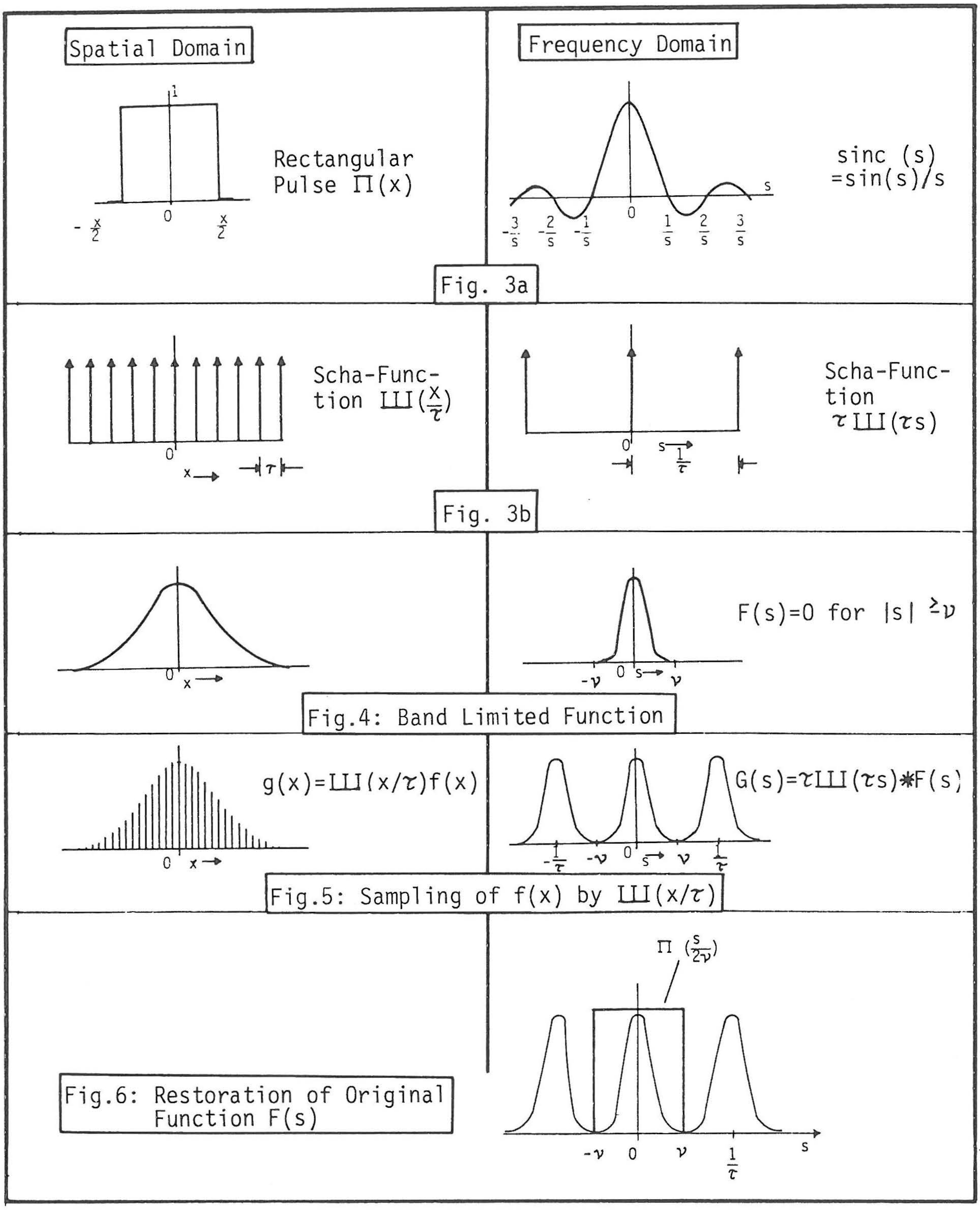


Fig. 3a

Fig. 3b

Fig.4: Band Limited Function

Fig.5: Sampling of f(x) by Ш(x/τ)

Fig.6: Restoration of Original Function F(s)

$$F(s) = G(s)\,\Pi\left(\frac{s}{2\nu}\right) \qquad (6)$$

$$f(x) = \mathcal{F}^{-1}\left\{G(s)\,\Pi\left(\frac{s}{2\nu}\right)\right\} = g(x) * \frac{\sin(2\pi\nu x)}{2\pi\nu x} = \int_{-\infty}^{+\infty} g(x)\,\frac{\sin(2\pi\nu\, x-\tau)}{(2\pi\nu\, x-\tau)}\,d\tau \qquad (7)$$

$$f(x) = \sum_{n=-\infty}^{n=+\infty} f(n\tau)\,\frac{\sin(2\pi\nu\, x-\tau)}{(2\pi\nu\, x-\tau)}\,d\tau \qquad (8)$$

taken as

$$\tau \leq \frac{1}{2\nu} \quad , \qquad (5)$$

full resolution of f (x) is preserved (Fig. 5, right side). (5) is called the "sampling theorem".

Restoration of original F (s) from sampled G (s) may be done by isolation F (s) (Fig. 4, right side) in G (s), multiplying G (s) by a rectangular pulse of 2 ν width (Fig. 6, Equ. (6), "Low pass filtering"). The original function in the spatial domain is obtained by the inverse FOURIER transform, applying the convolution theorem (PRATT S. 14, LÜKE S. 22) and the convolution integral (7). Finally, f (x) is represented by (8): the original function is restored from the sampled values f ($n\tau$), interpolating in between by "sinc"-functions sin ($2\pi\nu x - \tau$) / ($2\pi\nu x - \tau$).

Consequently, digital processing of photographic imagery has to observe following conditions, if preservation of resolution is desired:

1. Sampling at a rate of $\tau \leq 1/(2\nu)$, where ν is the frequency limit of the photographic image
2. Display of the sampled picture elements, interpolating by sinc functions

Condition 1 may be observed by taking the appropriate sampling frequency, whereas interpolation by sinc-functions would enormously expand the pixel number, so that it is practically not applied.

The sampling theorem demands digitization of two lines at least by 2 pixels, if proper interpolation is executed later on. As sampling is direction - depending and interpolation left out, sampling has to be done at higher rate. In practice,

$$\tau \sim 1/(3\nu) \qquad (9)$$

is taken as an appropriate value (see KONECNY / BÄHR / REIL / SCHREIBER 1979). The factor of 3 affects largely the economical considerations of digital versus analog image processing (see paragraph 4 and 5).

3. Geometrical Model

In photogrammetry, geometrical models describe the relation between image coordinates and object coordinates. For digital image processing, the entire original image has to be converted according to the specific task. This geometrical transformation is absolutely free from limitations and obeys only the mathematical formulation

$$(X, Y, Z)_{Object} = F(x', z')_{Image} \qquad (10)$$

consequently, digital image processing offers more geometrical flexibility than analog photographic processing. The advantages are obvious for processing of "non-conventional" imagery; they have however been shown for conventional photogrammetric imagery, too (see BÄHR 1978, KONECNY 1979).

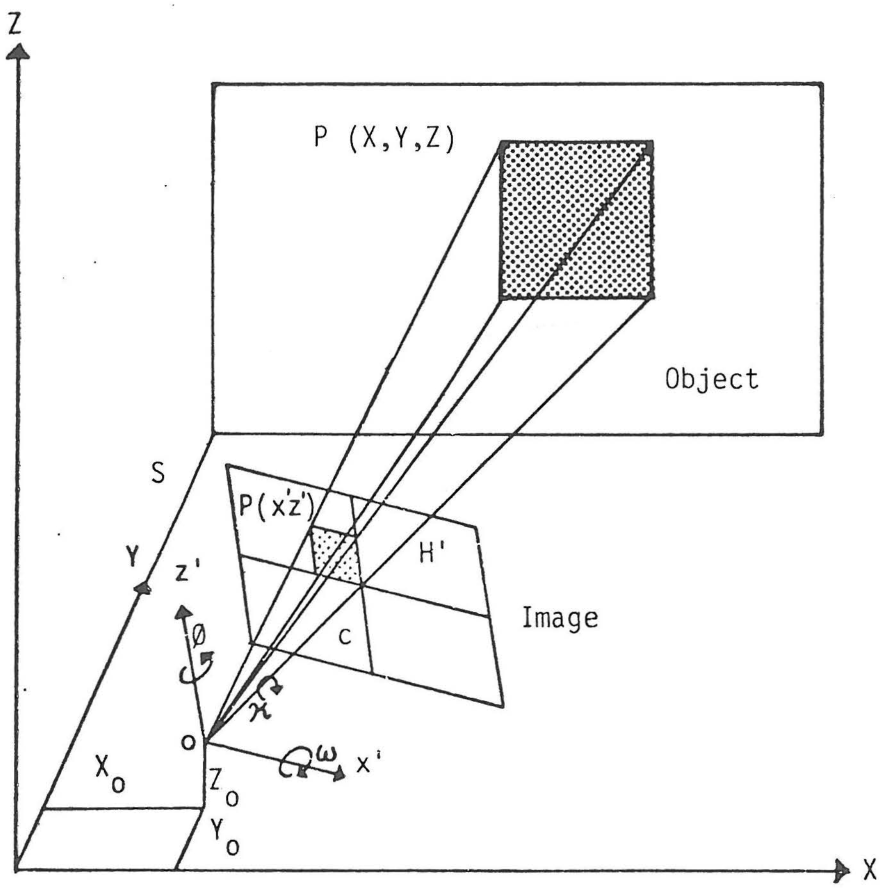


Fig. 7: Geometrical Model for Processing of Terrestrial Imagery

We restrict the geometrical transformation to linear processing of plane objects. Fig. 7 specifies the conditions for this case. The object plane is parallel to the X/Z-plane, at a distance of S. The exterior orientation of the image is described by X_o, Y_o, Z_o and ϕ, ω, κ. An object point $P(X, Y, Z)_i$ may be written by the collinearity equations

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_i = \lambda \, \underline{\underline{D}}_{\phi,\, \omega,\, \kappa} \begin{pmatrix} x' \\ c \\ z' \end{pmatrix}_i + \begin{pmatrix} X_o \\ Y_o \\ Z_o \end{pmatrix} , \qquad (11)$$

where λ is a scale factor and $\underline{\underline{D}}_{\phi,\, \omega,\, \kappa}$ the orientation matrix

$$\underline{\underline{D}}_{\phi,\, \omega,\, \kappa} = \begin{pmatrix} \cos\kappa \cos\phi - \sin\kappa \sin\omega \sin\phi & \cos\kappa \sin\phi + \sin\kappa \sin\omega \cos\phi & -\sin\kappa \cos\omega \\ (a_1) & (a_2) & (a_3) \\ -\cos\omega \sin\phi & \cos\omega \cos\phi & \sin\omega \\ (b_1) & (b_2) & (b_3) \\ \sin\kappa \cos\phi + \cos\kappa \sin\omega \sin\phi & \sin\kappa \sin\phi - \cos\kappa \sin\omega \cos\phi & \cos\kappa \cos\omega \\ (c_1) & (c_2) & (c_3) \end{pmatrix} \qquad (12)$$

After shifting O into the origin of the X/Y/Z-system and modificating equation (11) we obtain the object coordinates X, Z as a function of image coordinates x', z' according to (10):

$$X = S \frac{a_1 x' + a_2 c + a_3 z'}{b_1 x' + b_2 c + b_3 z'}$$

$$Z = S \frac{c_1 x' + c_2 c + c_3 z'}{b_1 x' + b_2 c + b_3 z'} \qquad (13)$$

$$Y = S = \text{const.}$$

An image display of the object has to use a scale factor, which may be set by manipulating S. If the object shall not be displayed in the X/Z-plane, the coordinates (13) have to be changed digitally taking

$$(\bar{X}, \bar{Y}, \bar{Z}) = G\,(X, Y, Z) \qquad (14)$$

which allows e. g. transformation of perspective center and viewing angle as well as distortion of the object surface itself (unrolling a cylindrical facade: BÄHR 1978; flattening of a globe: VOZIKIS 1979).

From (13) the parameters $a_1 \ldots c_3$ may be determined by least squares adjustment, taking control points in the object system X,Y,Z if the orientation is not known a priori.

4. Geometrical Rectification

Once the orientation parameters are known, a geometrical rectification is possible by an ordinary rectifyer, introducing ϕ, ω, κ directly. However, the instrumental scale is limited, for a ZEISS SEG V approximately at $\phi = \omega = 6^{\circ}$, consequently the rectification can there only be generated by multiple processes.

Digital rectification allows a straight forward approach, supposing digitized data. Presently, processing large amount of picture elements ("pixels") still leads to severe computing problems, which will be overcome in the near future by new generations of computers. After digitization of the photographic image observing the sampling theorem (see paragraph 2), digital rectification is recommended to be executed by the "indirect" method, explained by Fig. 8: Taking the regular pixel pattern of the r e c t i f i e d image, appertaining pixel coordinates in the distorted image are computed by (13), and their interpolated grey values are transferred.

If the geometric distortions and pixel number are large, rectification has to be done by segments (Fig. 8: 1 a, b, c, d) in order to maintain

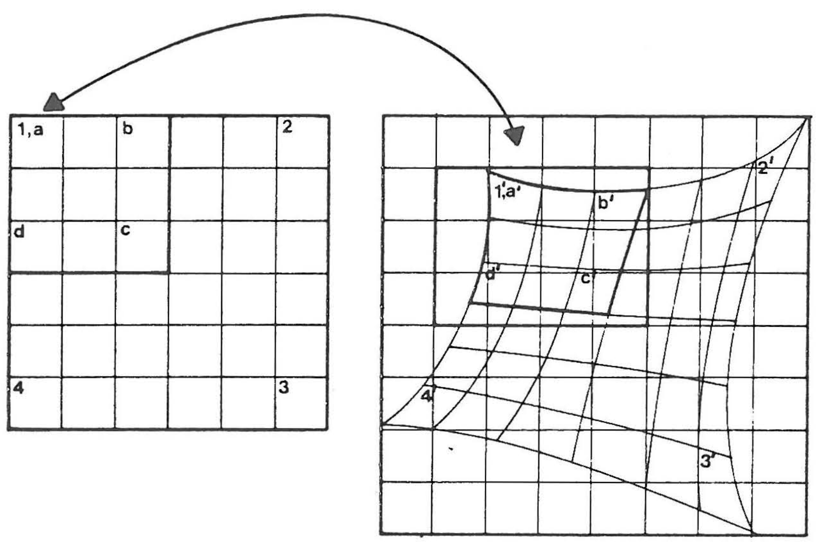
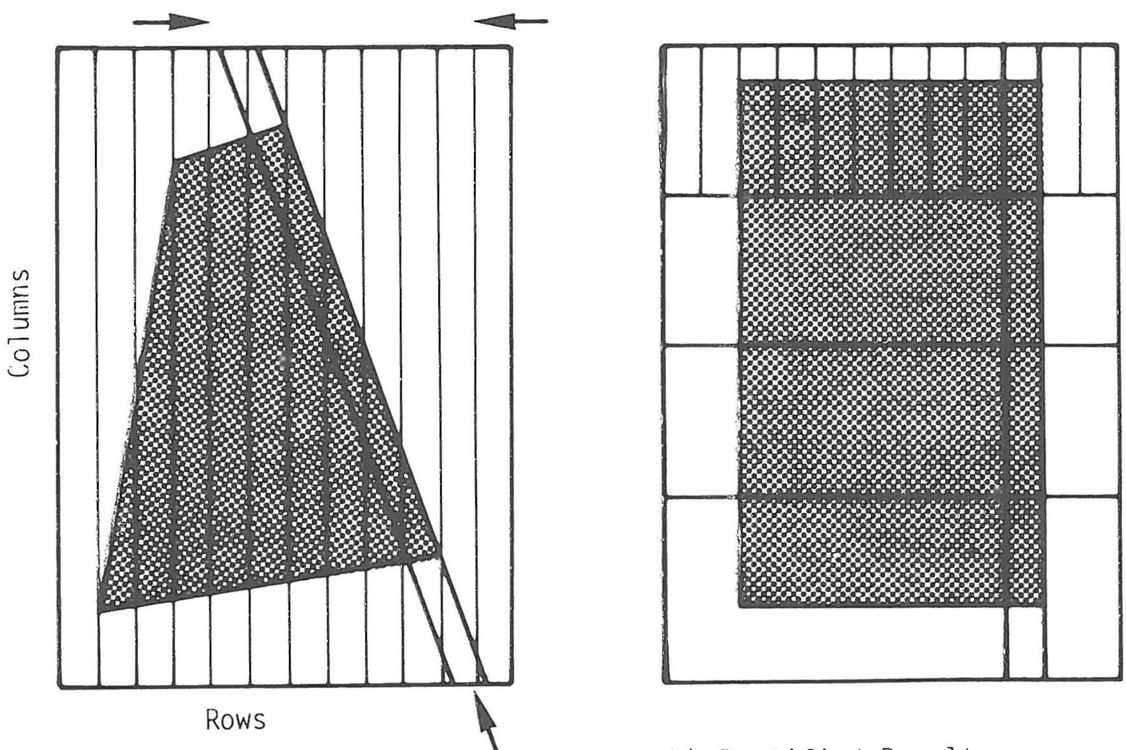


Fig. 8 : Digital Geometrical Processing; Indirect Method

reasonable computing time +). One segment has to fill the computer's core memory, avoiding time consuming frequent access to peripherel storage media.



a) Distorted Original b) Rectified Result

Fig. 9: Segmentation Procedure (Priciple)

+) Moreover, for a segment a simpler geometrical model may be taken than for the entire image (see SCHUHR 1980)

For example, rectification of 1 row from Fig. 9b affords approximately 250 rows in the computer's core memory, resulting in $0{,}45 \cdot 10^6$ pixels (see Fig. 9 a). As this number exeeds largely the available space of the used CDC CYBER 73/76 machine, segmentation had to be established as shown by Fig. 9 b. Within the segmented bands, rectification was done by the indirect method.

Note: Rectification accuracy is established by the geometrical model
Rectification econmomy is established by the rectification procedure.

5. Results from Digital Processing of Photogrammetric Imagery

Object of practical investigation were a building of Hannover University (Fig. 10 a) and a test target (Fig. 11 a). In order to keep computing time short, sampling of the original imagery (UMK JENA 13/18, c = 100 mm) was done by 100 µm x 100 µm pixel size (OPTRONICS machine of the Institut für Photogrammetrie, Hannover). Resolution of the photography was determined by the sector stars of the test target, which demonstrated a resolution of 33 linepairs / mm of the original material. According to paragraph 2, one linepair has to be sampled by 3 pixels in order to preserve full resolution of the original in the digitized version.

The original images have a format of 120 mm by 160 mm. This leads to $1{,}9 \cdot 10^6$ pixels for 100 µm sampling. Correct sampling of 3 pixels per linepair affords a pixel size of 1/ (33 · 3) mm = 10 µm, resulting in $190 \cdot 10^6$ pixels altogether. This number can hardly be handled with computers available today.

Object	ϕ^g	ω^g	κ^g	Pixel Number Original	Pixel Number Original	Sections	Computing Time (CDC CYBER 73/76)
							(sec)
University Buildung	0	33	0	$2{,}25 \cdot 10^6$	$1{,}70 \cdot 10^6$	12	62,7
						8	53,7
						7	44,0
University Building (Fig. 10)	23	33	0	$2{,}19 \cdot 10^6$	$1{,}75 \cdot 10^6$	8	46,2
Test Target (Fig. 11)	38,5	40,1	-2,7	$2{,}62 \cdot 10^6$	$1{,}50 \cdot 10^6$	8	51,9
						6	45,1
						3	33,6

Table 1: Results +) of different approaches for geometrical rectification

+) Software development and digital image processing by cand. geod. E. JÄGER, Hannover University

Fig. 10a(left):
University Bld.
Original UMK

$\phi = 23^{g}$
$\omega = 33^{g}$
$\kappa = 0^{g}$

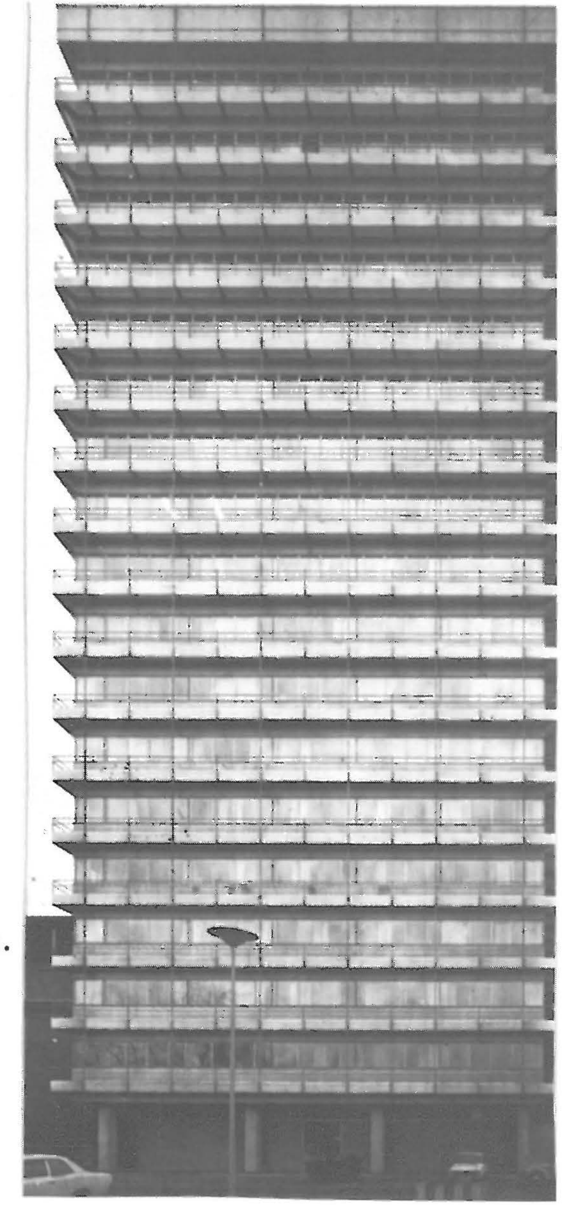
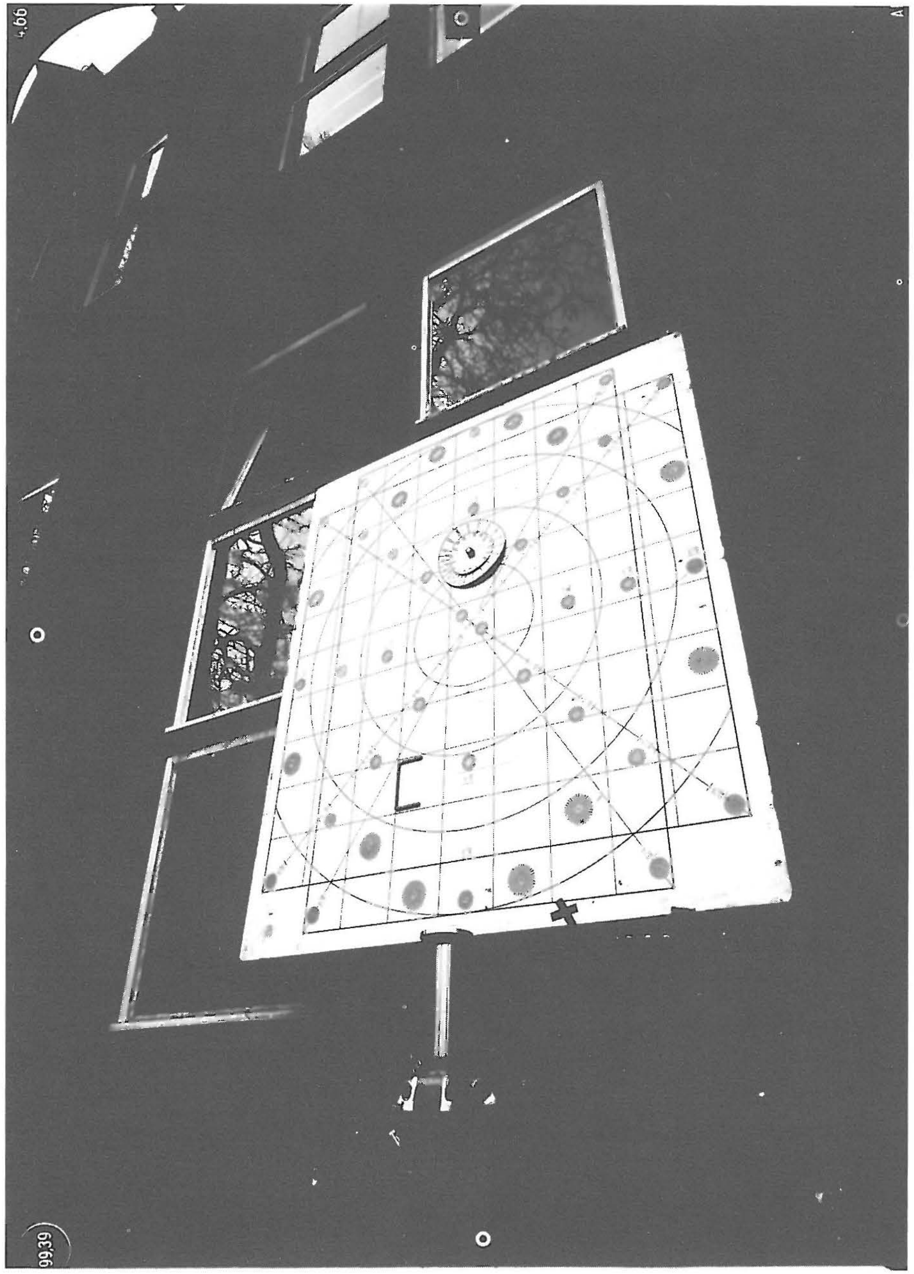


Fig. 10b(right):
University Bld.
Digital Rectific.

|——| Corresponds to 5m



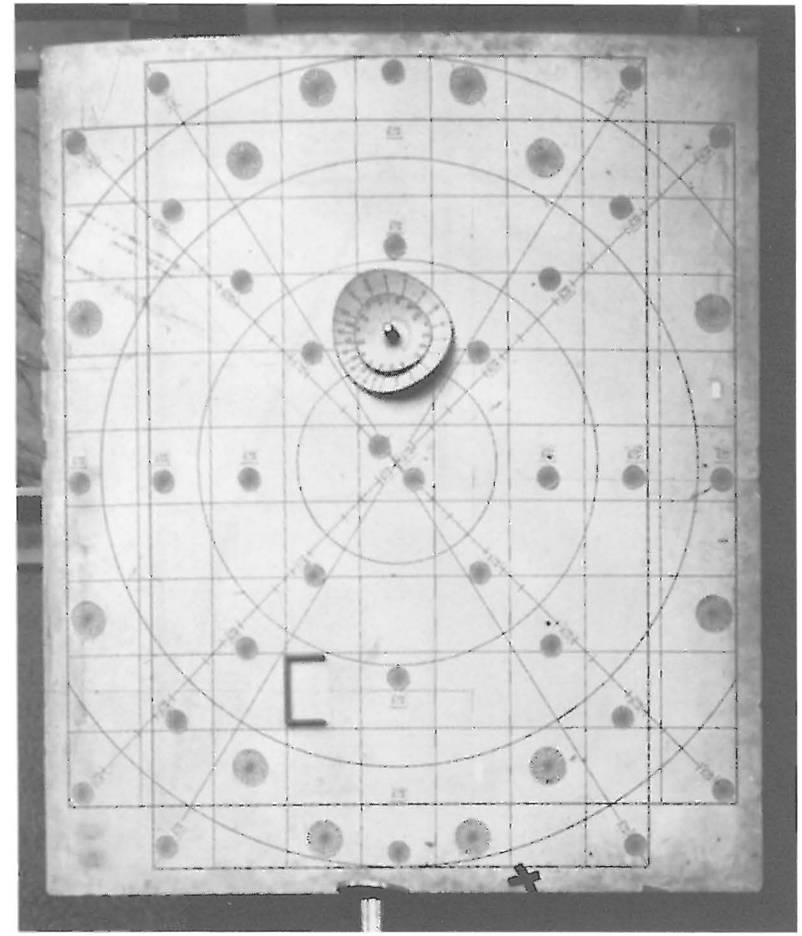
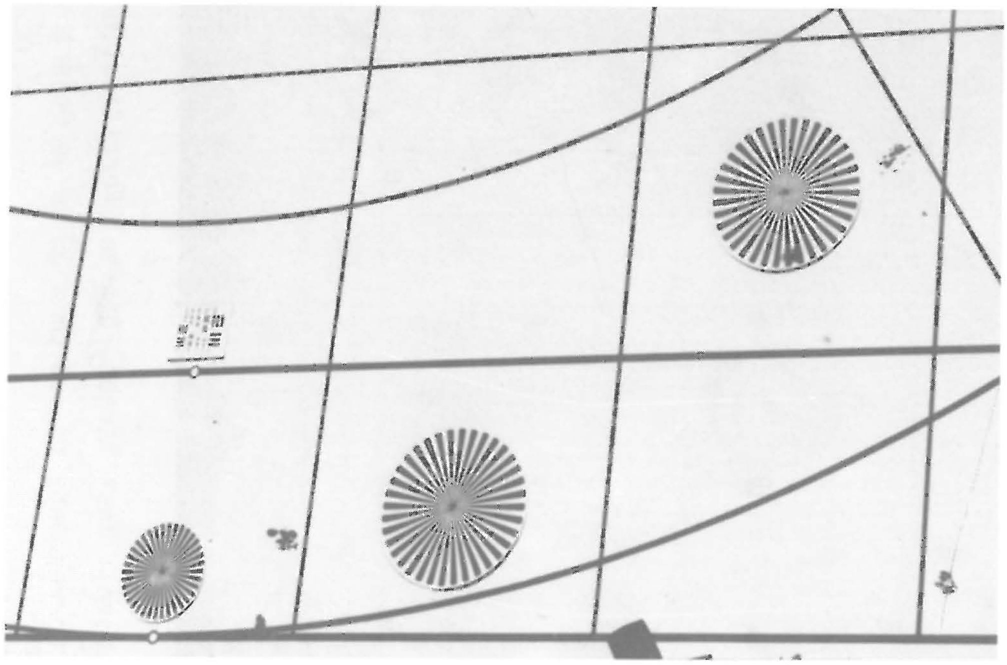
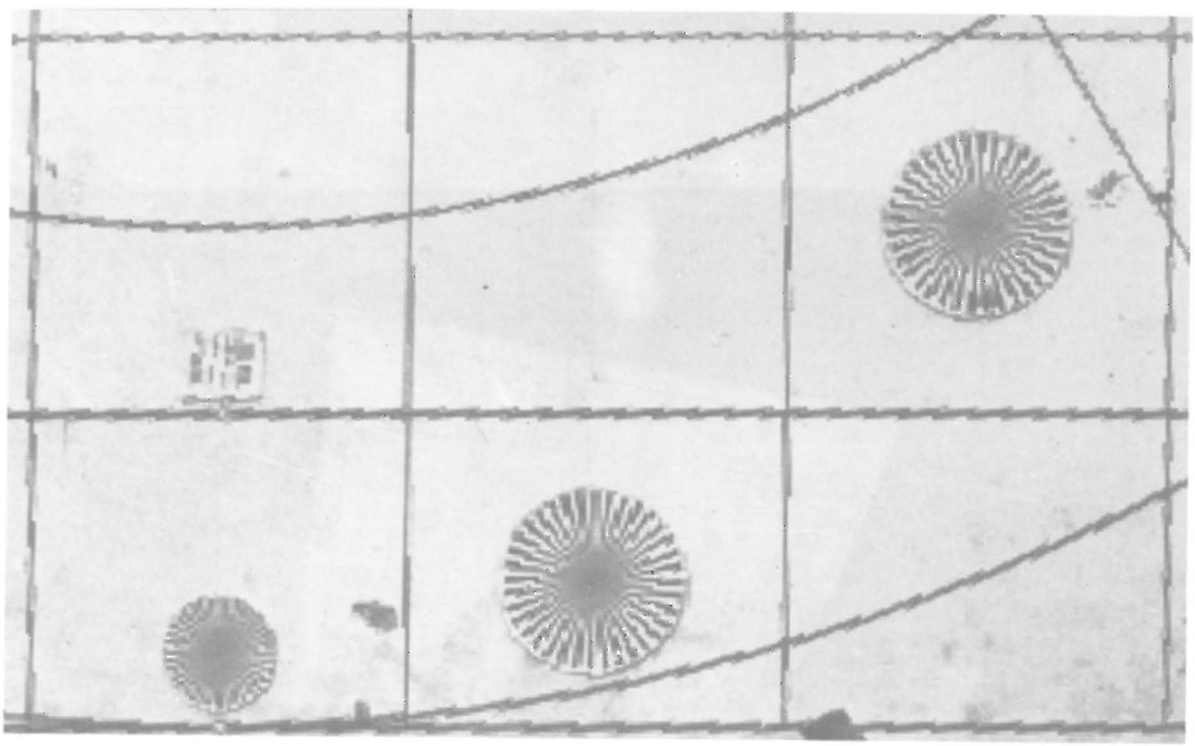


Fig. 11b (above): Test Target, Digital Rectification
1 Quadrat Corresponds to 15 cm x 15 cm in Object

Fig. 11a (left): Test Target , Original UMK Image
$\phi = 38,5^{g}$, $\omega = 40,1^{g}$, $\kappa = -2,7^{g}$



a



b

Fig. 12: Enlarged Sections from Fig. 11 (Factor of 5)
1 Quadrat Corresponds to 15 cm x 15 cm in the Object

Table 1 lists the results obtained from digital rectification of the images. For the University building, two different photos were evaluated, one with $\phi = 23^g$ (Fig. 10), another with $\phi = 0^g$. The computing time depends very much on the number of sections formed (see paragraph 4, Fig. 9), i. e. on the efficient use of the available core memory. The computing time is in correspondance with the values for digital rectification of a cylindrical facade (BÄHR 1978).

The quality of the resulting rectified imagery is very much affected by poor resolution because of "undersampling", by the factor of 10, which yields resolution of only 3,3 linepairs per millimeter. This effect is much more obvious for the test target than for the University building. In order to visualize the undersampling effects, Fig. 12 shows parts of Fig. 11, enlarged by the factor of 5. At the sector stars, typical moiré pattern ("aliasing") occurs.

The examples (Fig. 10 b, 11 b) demonstrate, however, that digital rectification is principally possible. The orientation parameters ϕ, ω, κ have been determined in situ by a theodolite for the University building, whereas they were computed by analytical space intersection for the test target. Remaining distortion of horizontal lines at the upper part of the test target are already in the original photography (Fig. 11 a), due to distortion of the target plate.

The actual advantages of digital image processing versus analog procedures are in the "semantic" field, as stated above. Fig. 14 shows two examples for digital manipulation of the image content. The histogram of a rectified image from the university building (for $\phi = 0^g$, not shown!) is displayed in Fig. 13. The main information of the building itself lies between the grey values 80 and 180. Fig. 14 a shows the image after transformation of the original grey values G into G':

$$0 \leq G \leq 80 : G' = 0$$
$$80 \leq G \leq 180 : 0 \leq G' \leq 255 \text{ (linearization)}$$
$$180 \leq G \leq 255 : G' = 255$$

This manipulation results in an image with much higher contrast than the original one, which would not have been available by analog photographic means.

Fig. 14 b finally demonstrates a line extraction effect. To keep noise low, a moving average was formed (original image $\phi = 0^g$) with following histogram processing.

All subroutines used for geometric and semantic digital image processing are part of the MOBI modular image processing package at the Institut für Photogrammetrie at Hannover University. Originally developed for processing remote sensing data, MOBI can directly be applied to conventional photogrammetric data too, a task, which will become actual in the near future.

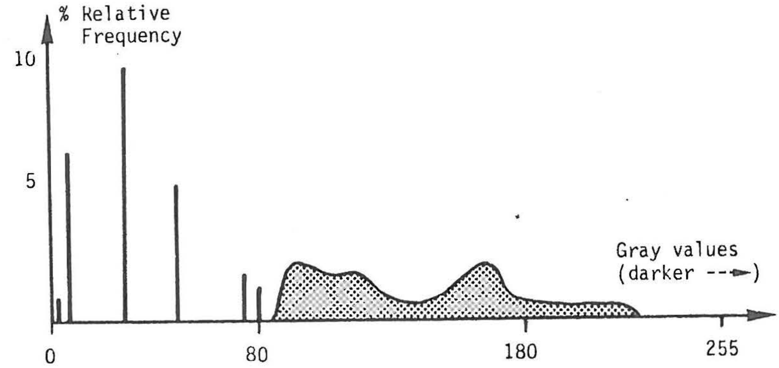


Fig. 13:
Original Histogram

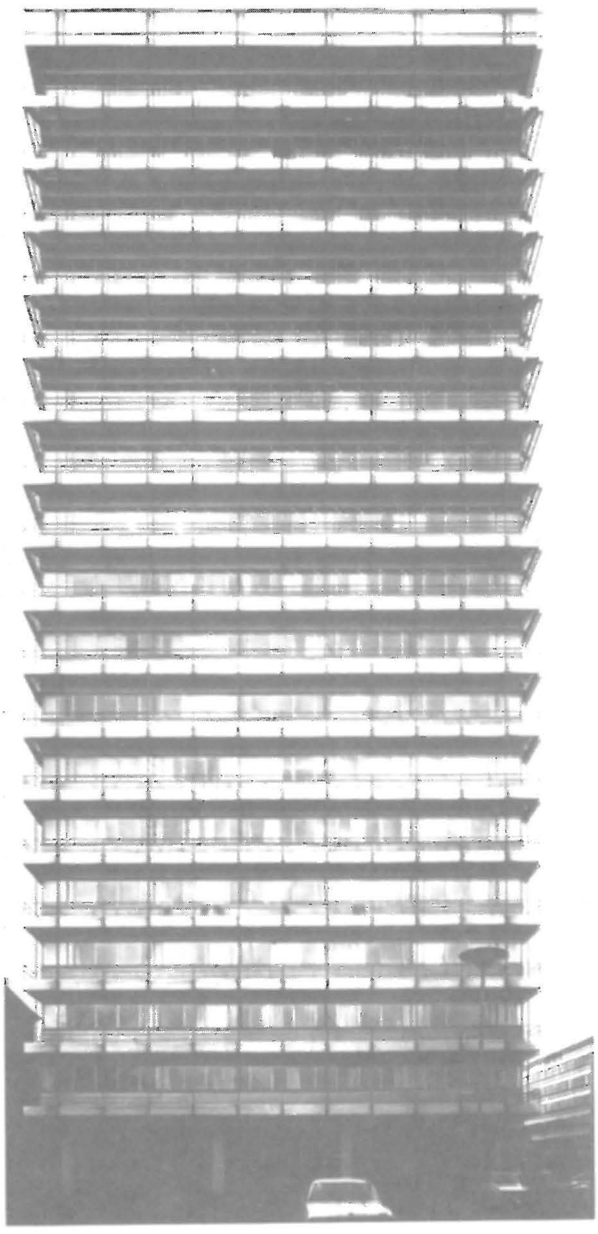


Fig. 14a: Histogrammanipulation

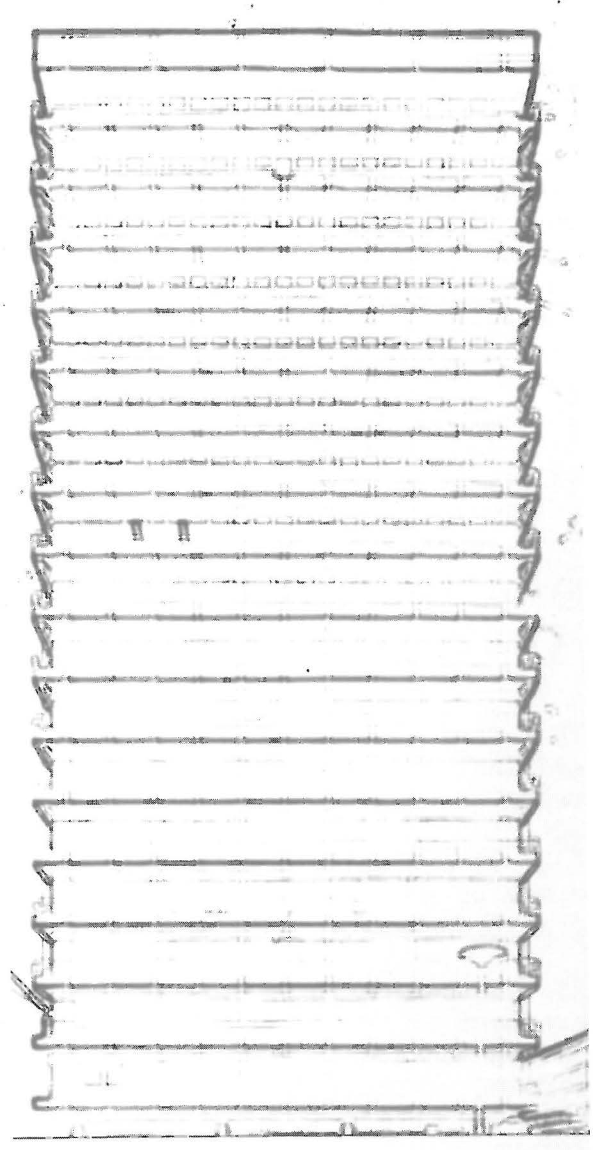


Fig. 14b: Line extraction

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