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Reprint from:

INTERNATIONAL CONFERENCE AND WORKSHOP
ON
ANALYTICAL INSTRUMENTATION

RADARGRAMMETRY AND DIGITAL PHOTOGRAMMETRY

PP. 141-171

ANALOG TO DIGITAL NOVICE TO EXPERT

PHOENIX • 1987 • ARIZONA

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AND
ASPRS
NOVEMBER 2-6, 1987
PHOENIX, ARIZONA
USA

RADARGRAMMETRY AND DIGITAL PHOTOGRAMMETRY

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6 November 1987

Dr. Franz W. Leberl
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Dr. Franz W. Leberl was born in 1945. He received the Dipl. Ing. Degree in geodetic engineering in 1967 and the Dr. Tech. Degree in 1972, both from the Technical University, Vienna, Austria.

He has worked at the International Institute for Aerial Surveys and Earth Sciences, Delft and Enschede, The Netherlands, from 1969 to 1974. From 1974 to 1976, he was a Research Associate at the Jet Propulsion Laboratory, Pasadena, CA. From 1976 to 1984, he held an appointment at the Technical University, Graz, Austria, as a Professor of Photogrammetry and Remote Sensing. Simultaneously, he was founder and director of the Research Institute for Image Processing and Computer Graphics at the Graz Research Center in Austria. In 1984-1985 he was with Markhurd Corporation in Minneapolis, Minnesota. In 1985 he formed VEXCEL Corporation in Boulder, CO. He is the author of more than 100 articles on many aspects of photogrammetry, image processing, remote sensing, and in particular on radargrammetry.

Dr. Leberl was recipient of the Otto von Gruber Gold Medal of the International Society for Photogrammetry and Remote Sensing in 1976.

CONTENTS

This presentation addresses the future of the fields of geometric SAR image processing and of photogrammetry. The subjects are separate but relate in their future roles. An all-digital sensor-, analysis- and data presentation system is anticipated. It is trivial to predict such a future capability, it is not easy to chart the course to this future, nor to see clearly the milestones on this course.

CURRENT STATUS OF SAR-RADARGRAMMETRY

Cartographic Standards

STARMAP

Ice Motion from SAR Time Series

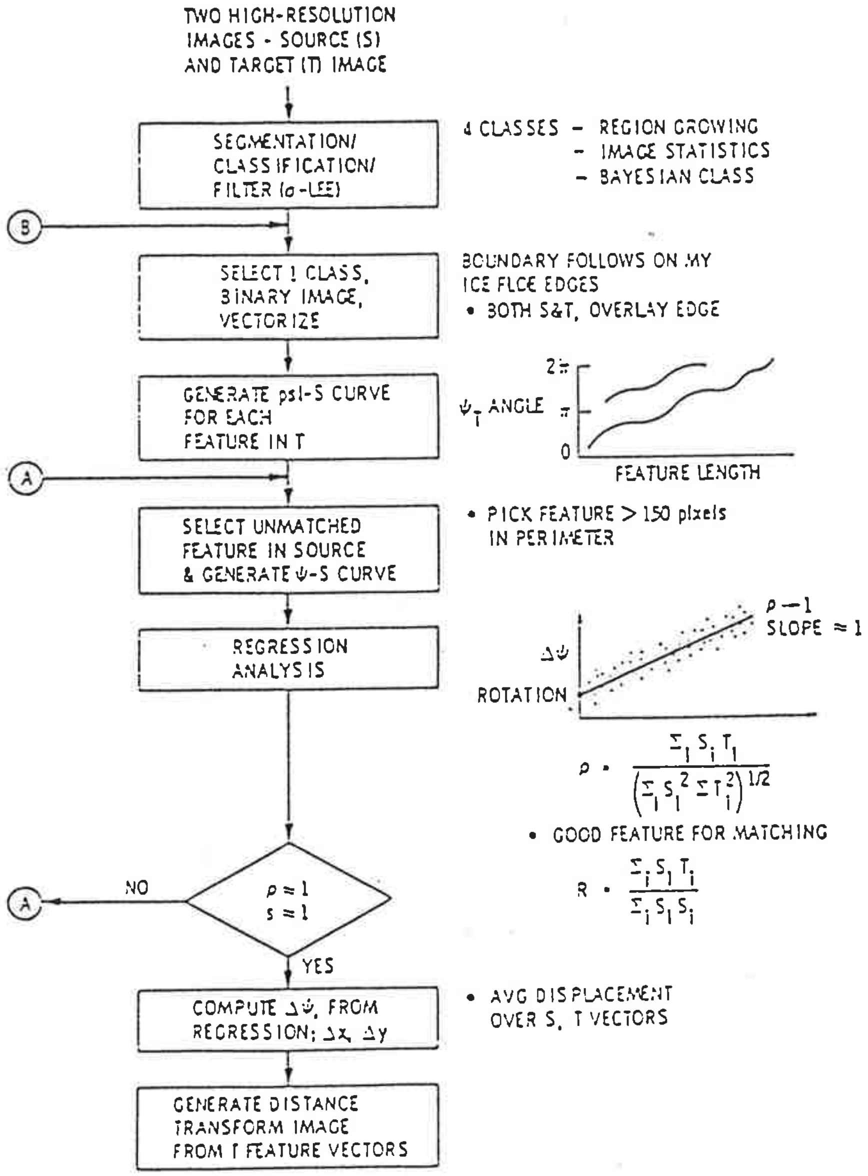
SIR-B Space Shuttle Radargrammetry

We discuss the current value system of cartography and its inability to deal with the new opportunities of remote sensing. Clearly the standards of height, planimetric accuracy and of image resolution that exist in classical cartography set standards that do not give remote sensing data much of a role in mapping. The easiest standard to meet is planimetric accuracy, since this is simply a factor defined at the presentation scale at 0.2 to 0.5 mm. Height is at 5 to 20 m at scales 1:50,000 and smaller. Detail must normally be available at a resolution typified by an image scale of $sqrt(m_k)*200$. This results in 1 to 2 m ground resolution for scales 1:50,000. The escape from this inutility of remote sensing imagery is in the form of image maps. We see these from LANDSAT, SPOT and from radar. STARMAP is a concept of a 1:50,000 image map from X-band SAR images flown with an aircraft. It exists at a cost of about $ 10.-- per sqkm. Other discussion items deal with a clear and unique mapping application for SAR: sea-ice kinematics. Finally, the current situation os SAR is dominated by the SIR-B shuttle radar experiment.

ICE MOTION ANALYSIS

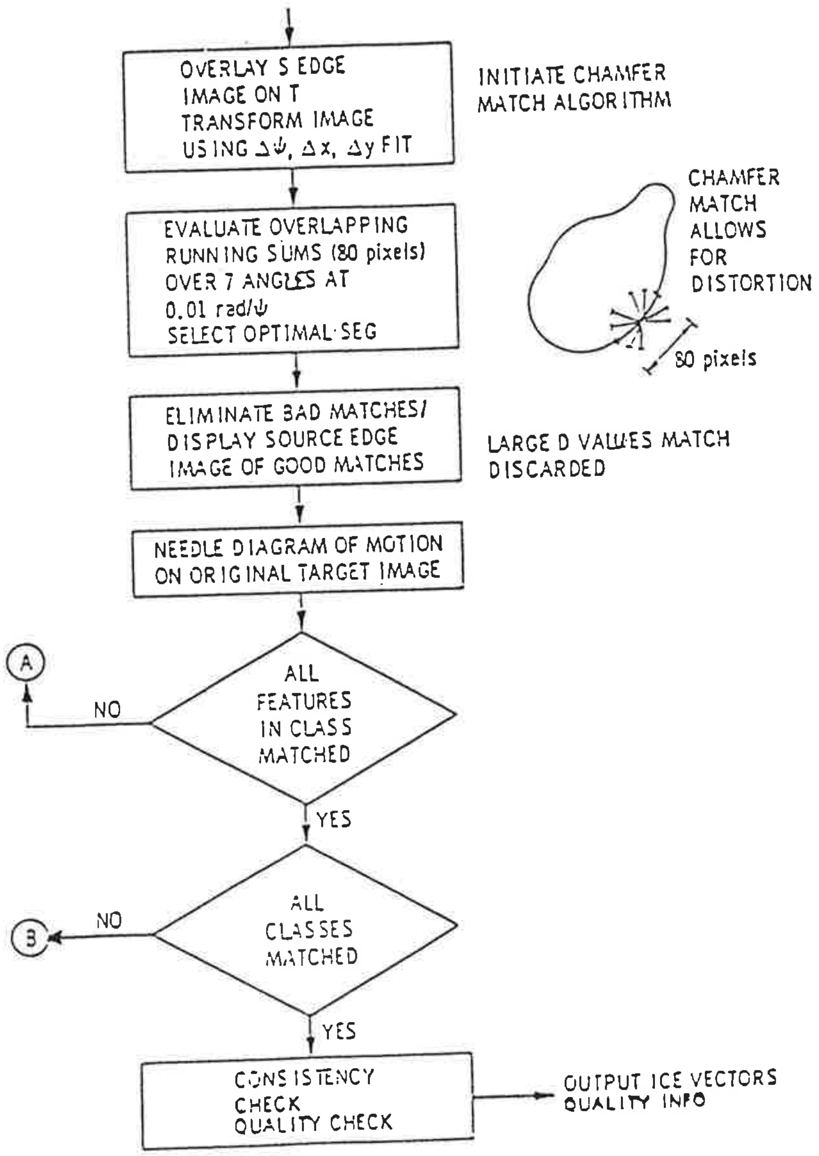
JPL

MATCHING



JPL

ICE MOTION ANALYSIS
MATCHING (Cont'd)



DISTANCE ARRAY PRODUCED BY CHAMFERING THE BOUNDARY

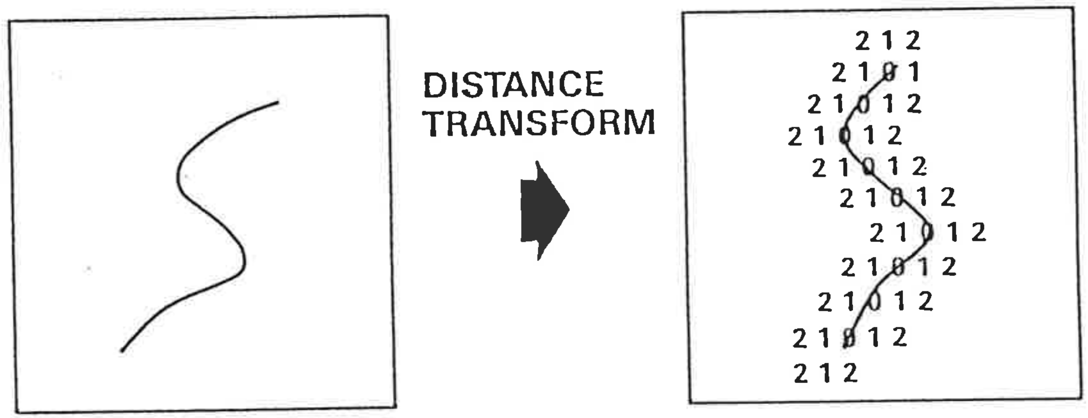


IMAGE 2 FEATURE (F)

SAMPLE DISTANCE ARRAY (EUCLIDEAN DISTANCES)

Table 1: SIR-B images forming stereo pairs.

Nr.	Site	Data take	Look angle off-nadir (°)	Ground Resolution (m^2) range x azimuth
1	Gordon la Graza	39.4	57	16 x 34
2	- " -	55.4	51	17 x 29
3	- " -	87.4	28	30 x 21
4	Argentina	104.4	56	16 x 34
5	- " -	88.4	51	17 x 29
6	- " -	72.4	43	20 x 23
7	- " -	56.4	33	26 x 23
8	Illinois	49.2	28	30 x 21
9	- " -	97.2	29	29 x 21
10	Jose de S.Martin	92.8	28	27 x 23
11	"	76.8	40	20 x 37
12	"	56.4	30	26 x 23
13	"	72.4	41	20 x 34
14	"	104.4	55	16 x 34
15	Rio Cisnes	76.8	43	20 x 37
16	"	44.8	—	—
17	"	92.9	—	—
18	Australia	51.8	15	52 x 26
19	"	67.8	33	24 x 24
20	"	83.8	47	—
21	"	83.8	51	18 x 24
22	Bangladesh	66.2	40	22 x 26
23	"	82.2	22	38 x 28
24	Nevada	82.2	22	38 x 28
25	"	66.2	39	22 x 25

Table 2: Stereo-coordinate accuracies obtained from the image pairs listed in Table 1.

Area	Stereomodel Data take	Intersection angle (°)	Coordinate errors in meters North	East	Height
Gordon la Graza	04/88	5	67	78	86
	88/72	8	78	70	110
	72/56	10	65	85	67
	104/72	13	77	73	65
	88/56	18	59	74	59
	104/56	23	62	49	62
Mt. Shasta	39/55	6	106	106	125
	55/87	23	44	75	53
	39/87	28	91	100	73
Illinois	49/97	57	240	185	10
Jose de San Martin	92/76	11	72	118	26
	56/72	11	76	155	42

FUTURE DEVELOPMENTS

- **Satellites**
- **Technological Advances**
- **INS/GPS**
- **Integrated Digital Image Processing / Coordinate Processing**
- **From Classical Mapping to Monitoring**

We need to anticipate the above topics to dominate the progress of radargrammetry. We expect

European ERS-1 staellite in	1990
Japanese ERS-1 satellite in	1992
Canada's Radarsat in	1992
NASA's SIR-C in	1991
NASA's Magellan mission in	1989
NASA's EOS in	1994

We need to begin to anticipate the monitoring of phenomena so that data bases are being kept updated. SAR may play a role in this function, since only changes are needed and an all time, all weather capability may be advantageous. Should a digital satellite sensor not be an all-weather sensor if used for monitoring?

TECHNOLOGICAL ADVANCES

- Geometric Resolution
- Multiple Azimuth and Look Angle SAR
- Multiple Polarization SAR
- Shape from Shading Concepts Development
- Platform Positioning (INS, GPS)
- Digital Image Processing Technologies

Significant technological advances are always seen in geometric resolution. SAR may offer some significance in the satellite area due to its independence of distance from the object. 0.5 meter resolution from space is feasible once the data rates can be handled at lar- swaths. Multiplicity in coverages are also a major promise once the processing problem is mastered. The great advantage of camera imagery is in geometric strength. This may sneak in via clever uses of GPS-concepts and therefore also be available for dynamic (or kinematic) imagery. Digital image processing technology may become the great "equalizer": all types of imagery have a role to play in a synergistic, integrated, fused, merged system.

INS / GPS REFINEMENT

$$X_o = \bar{X}_o + \bar{a}_x + \bar{b}_x \bar{t} + dX'_o \cdot dt;$$
$$Y_o = \bar{Y}_o + \bar{a}_y + \bar{b}_y \bar{t} + dY'_o \cdot dt; \qquad (1)$$
$$Z_o = \bar{Z}_o + \bar{a}_z + \bar{b}_z \bar{t} + dZ'_o \cdot dt.$$

$$t = \bar{t} + a_t + b_t \bar{t} + (c_t \bar{t}^2) = \bar{t} + dt. \qquad (2)$$

$$X_o = \bar{X}_o + \{\bar{a}_x + \bar{b}_x (\bar{t} + a_t + b_t \bar{t} + c_t \bar{t}^2) + d\bar{X}'_o (a_t + b_t \bar{t} + c_t \bar{t}^2)\} = \bar{X}_o + dX_o$$
$$Y_o = \bar{Y}_o + \{\bar{a}_y + \bar{b}_y (\bar{t} + a_t + b_t \bar{t} + c_t \bar{t}^2) + d\bar{Y}'_o (a_t + b_t \bar{t} + c_t \bar{t}^2)\} = \bar{Y}_o + dY_o$$
$$Z_o = \bar{Z}_o + \{\bar{a}_z + \bar{b}_z (\bar{t} + a_t + b_t \bar{t} + c_t \bar{t}^2) + d\bar{Z}'_o (a_t + b_t \bar{t} + c_t \bar{t}^2)\} = \bar{Z}_o + dZ_o$$

$$dx = dX_o + H\, dZ_o/dt + \sqrt{r^2 - H^2}\, dY_o/dt;$$
$$dy = dY_o + H/Y\, dZ_o;$$

INS / GPS REFINEMENT

$$x + v_x = \tilde{x} + (a_x + b_x t + c_x t^2 + a_t \, dX_o' + b_t \, dX_o' t + c_t \, dX_o' t^2) +$$
$$+ H \, (b_z + 2c_z t + b_t \, dZ_o' + 2 \, dZ_o' t \, c_t) +$$
$$+ \sqrt{r^2 - H^2} \, (b_y + 2c_y t + b_t \, dY_o' + 2dY_o' \, t \, c_t);$$

$$y + v_y = \tilde{y} + (a_y + b_y t + c_y t^2 + a_t \, dY_o' + b_t \, dY_o' + c_t \, dY_o' \, t^2) +$$
$$+ H/Y \, (a_z + b_z t + c_z t^2 + a_t \, dZ_o' + b_t \, dZ_o' t + c_t \, c$$

Unknowns

a_x, b_x, c_x, a_y, b_y, c_y, a_z, b_z, c_z, a_t, b_t, c_t.

CURRENT STATUS OF DIGITAL PHOTOGRAMMETRY

Image Creation

Analysis

Data and Information Presentation

We can group technologies of photogrammetry into the above three categories. We have seen little advances in the aquisition of imagery: it is still the film camera as the main producer of data.

The advances in the analysis domain are moreprofound. But we have not much beyond the analytical plotter. Digital photogrammetry is not yet in existence except in some laboratories. The DCCS, Autoset/STARS and SPOT stereo software systems ar about the only visible tips of this technology. The DMA-modernisation project keeps meny hundreds of people employed. We need to see how well this approach of all-digital photogrammetry will work. A decisive factor is the increase in productivity. Here the current bottlenecks are in contour and planimetric feature mapping, not in aerial triangulation (1 hour of aerial triangulation may be followed by 6 hours of DEM/contouring and by 15 hours of collecting urban man-made features mapping.

We all like to look at the colour presentations of GIS data base contents. Computer graphics and simulation technology are creating great progress that benefits the mapping field. This may be less relevant than the GIS technology itself.

IMAGE CREATION

- SPOT
- MOMS and Stereo-MOMS
- Forward Motion Compensation
- Inexpensive Reusable Film Cameras in Space
- Linear Array Area Technology
- Real-Time versus Off-Line Image Creation

The civilian world would not have seen eloectro-optical scan imagery had it not been for space imaging. Interesting stereo concepts have been proposed, also in the USA, but Europe takes the lead (as in aerial cameras): SPOT (French) and MOMS (German) promise the relevant concepts of the future.

Camera design is not making much progress. FMC is an old concept revived for general use to improve exposure times for better contrast and resolution. A great concept is the reusable film camera in space as implemented by the USSR.

The future will be in array imaging, in a form discussed later. Close range situations will be more and more require real time imaging with array cameras.

DATA AND INFORMATION PRESENTATION TECHNOLOGIES

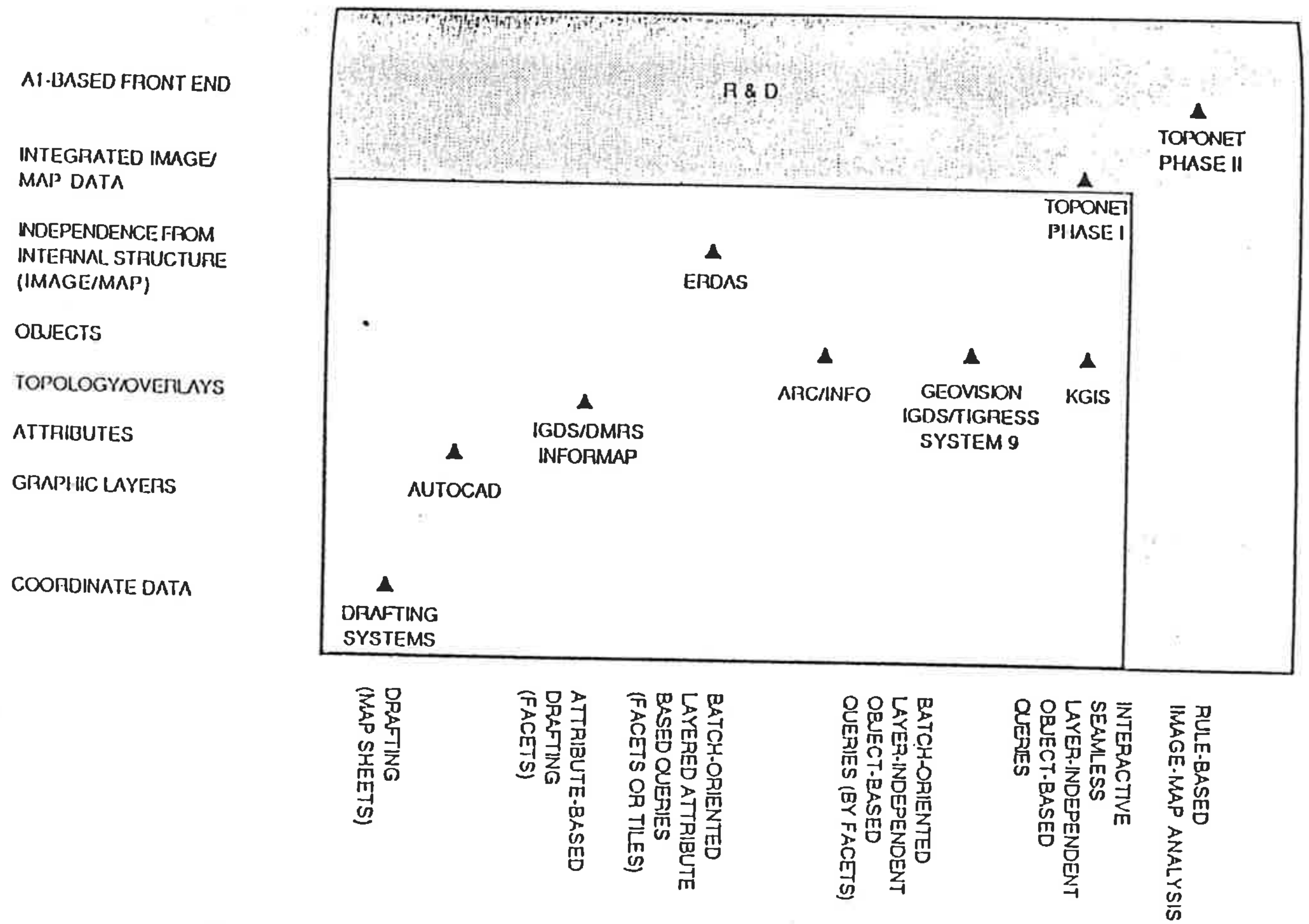
- Image Superposition
- Integration of Image and GIS
- Editing/Monitoring Support
- 2 1/2 Dimensional and Three-Dimensional Displays

Currently most unconventional data presentation techniques are still very painful to use. A color image of an area covered by a map data set is generated in enthousiastic "special effect" efforts made by dedicated young engineers.

The integration of imagery and GIS is much discussed but hardly available. Superposition is available, but that is not integration.

Interaction between the image and GIS data requires cross-fertilization of the analysis efforts.

We see more and more 2 1/2 displays coming on the market (stereo viewing). 3-d would be the holographic or similar techniques let the user walk through the object.



DATABASE COMPLEXITY VERSUS QUERY CAPABILITY
FIGURE 1.9

OPPORTUNITIES FOR AUTOMATION

- **Stereo-Model Set-Up**
- **Height Data Collection Using Image Parallax Detection**
- **Line Following**
- **Region Growing**
- **Tracking Correlation**
- **Image / Data Base Interactions (Image Map Matching)**
- **Change Detection**

This is an area of endless potential to attract human ingenuity. Many Ph.D. Theses will still be written on that topic.

Here are the greatest opportunities to improve throughput of the mapping process. Only stereo model set-up and height data extraction are topics that are understood to some extent.

The imagination can go wild on the speculation how to automate the collection of roads, drainage, man made features, in particular in urban areas. Current efforts of "built-up area detection", "automated feature extraction" etc. may me smiled upon in 30 years or so. But it is here that breakthroughs will happen that will truly be significant.

The most managable of the problrm domains is map updating if the "map" is a GIS.

WHY DIGITAL PHOTOGRAMMETRY ?

- **Automation**
- **Real-Time Applications Scenarios**
- **Increase in Data Extraction Throughputs (10 Times ?)**
- **Increased Spectral and Geometric Resolution**
- **Telemetering of Data**

Other reasons: Its fun.

But the proof of the concept is in productivity gains. Are these feasible ? Where should a 10 times throughput increase come from? Mapping from a stereo model in rural areas may take 10 hours, in an urban area 40 hours. How do we get this to 1 hour or 4 hours ?

DATA COLLECTION TECHNOLOGIES	STATUS			
	OPERATIONAL	APPLIED R&D	BASIC R&D	COMMENT
Manual Photogrammetry using plotters	Yes	None required	None required	Standard technique of database creation
Automated stereo correlation for DEM creation	Exists, but is hardly used	Addressed by Image Understanding program	Refine algorithms to increase accuracy, robustness, decrease cost	Manual methods are still more accurate
Semi-automated line-following in stereo model	None	No work visible	Need basic concept of hierarchial, anticipatory computations	Guided (tracking) correlation
Automated line following in stereo models	None	Robot vision with man-made objects in CAD	Natural outdoor scenes need considerable work	No work is visible with remote sensing imagery
Image segmentation and classification	Only in specific thematic applications	Image Understanding program	Work is on-going but for thematic uses	General purpose data extraction does not use stereo
Manual digitizing of maps	Yes	Improvements are proposed (aided-track cursors)	None	Standard technique of data extraction

(Semi-) automated digitizing of map separates	Partly	Rule-based interpretation of raw vector data	Automation is only possible with elaborate AI-based approaches	Only for simple contour lines and polygons
Manual updating of data from digital images	Systems fail to have sensor model	The subject is largely neglected	None	Tools are practically non-existent for using digital images
Semi-automated updating of data from single digital images	None	Image Understanding peripherally addresses the issue	Some "map-guided" image analysis is relevant	Date organization algorithms and systems are required to support automation (mono-plotting)
Semi-automated updating of data from stereo-pairs	None	None	None	Currently not addressed
Automated comparison of image and map data	No work addresses updating	Image Understanding research may address topic	Research may as part of the Image Understanding program	Visible work does not address the updating issue, but only the image feature recognition in the presence of map data
Direct elevation measurements from altimeters	None	Satellite-based concepts are often proposed	None	Semi-operational, but normally not useful since only inaccurate DEM is produced

THREE LINE ARRAY SCANNING

This may be the revolutionary concept to do away with the film camera after all. It simulates a frame camera in very sophisitica- ted manner that is actually superior to the camera as we know it.

This may, in conjunction with GPS etc, complete a system that is entirely digital from end to end.

Image correlationis a central element of the concept: it not only provides parallaxes for stereo computation of terrain or object shape, it also creates a parallax free stereo model for operator in spection.

The following is a review based on two pioneers of the concept: Otto Hofmann of MBB-Munich and G. Konecny. The original work on the subject is by E. Derenyi.

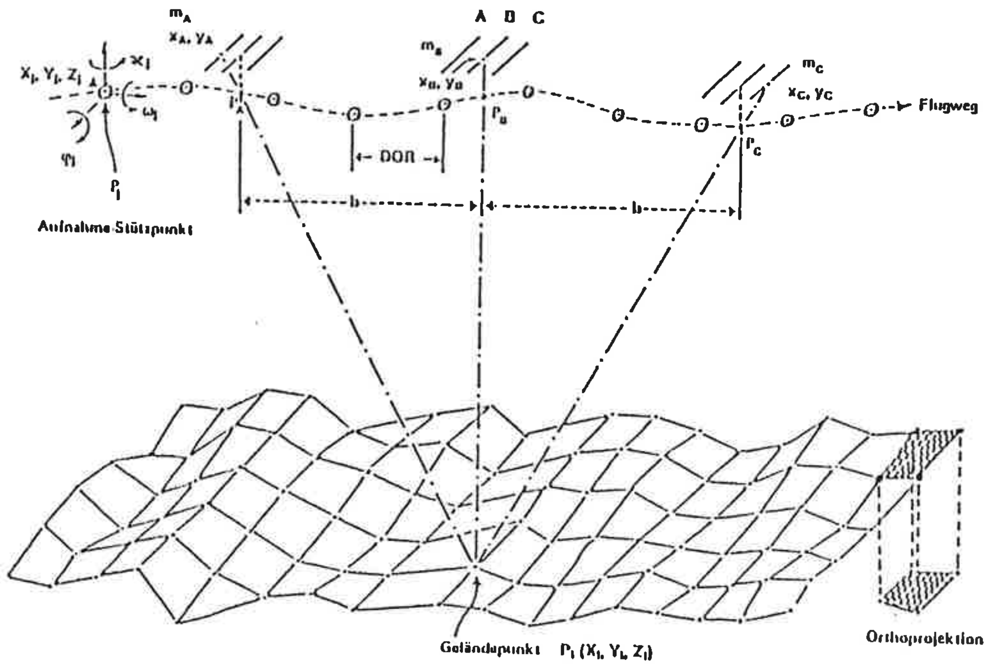


Abb. 1 DPS-Aufnahmeprinzip

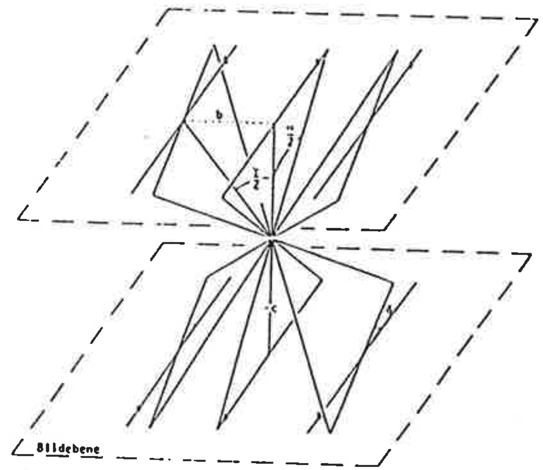


Abb. 1 Drehwinkel (+δ) der äußeren Bildzeilen

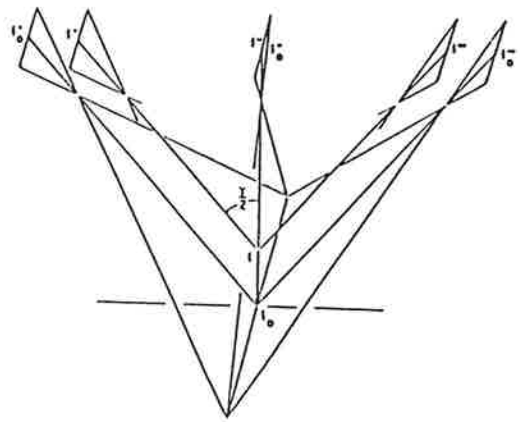


Abb. 2 Einfluß des Geländehöhenunterschiedes auf die Lineararray-Abtastung der voraus- bzw. zurückschauenden Sensorzeile

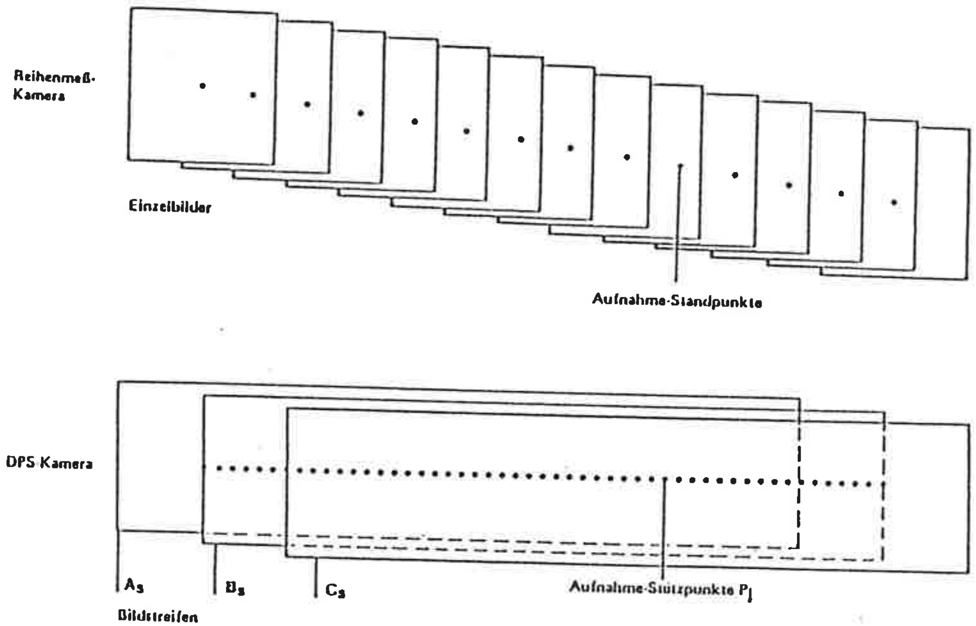
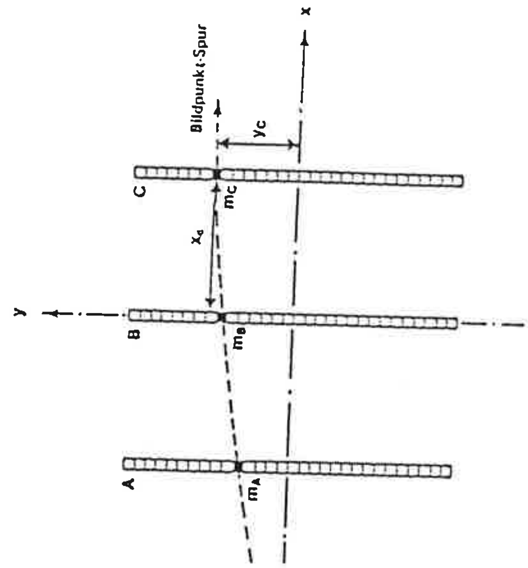
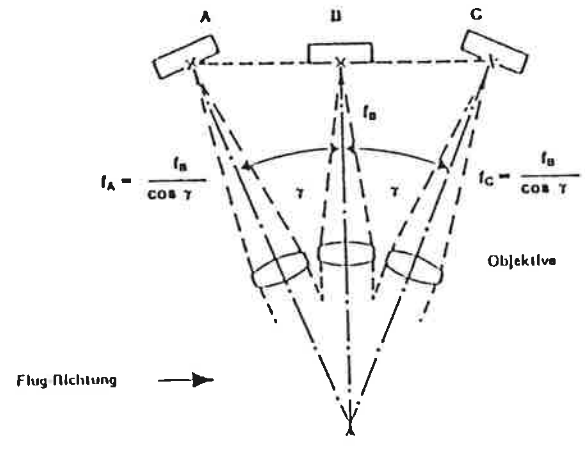


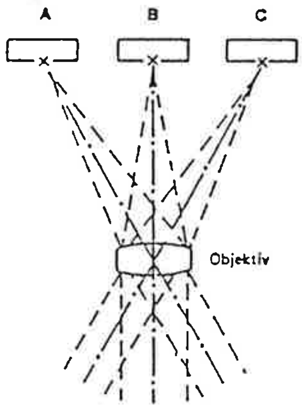
Abb. 2 Dreifache Bildstreifenüberdeckung der DPS-Aufnahme


Bildpunkt-Spur
x
y
y_C
A
B
C
m_A
m_B
m_C



b. Drei Objektive mit je einem Sensor

Abb. 4 Stereo-Abtaster mit drei Sensorzeilen



a. Sensoren in der Bildebene eines Objektives

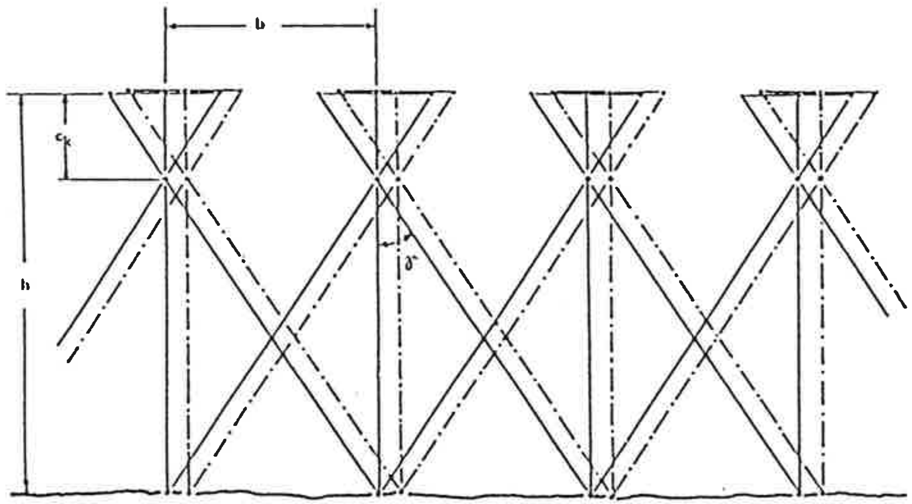


Abb. 6 Idealisierte Aufnahme mit Dreizeilen-Stereo-Abtaster

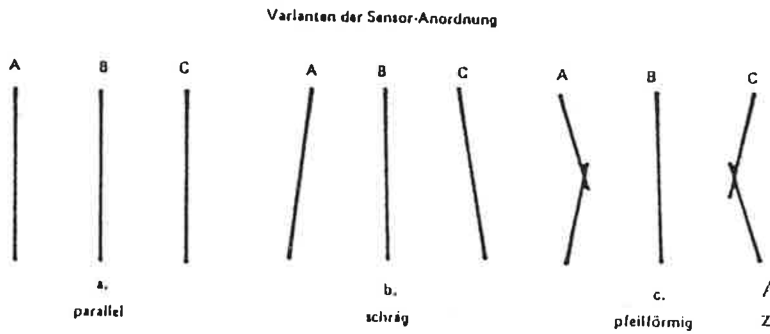
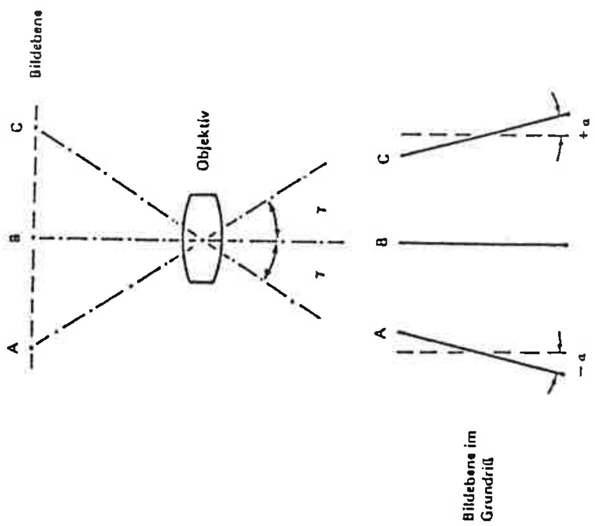


Abb. 7 Schrägstellung der Sensorzeilen A und C


Bildebene
A
B
C
Objektiv
A
B
C
+α
−α
Bildebene im
Grundriß