Digital Photogrammetric Imaging – Past, Present and Future
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40th Phot. Week, Stuttgart 1985
Ackermann, F.: Technology transfer – a glance back at 39 Photogrammetric Weeks
“... It can be stated ... that the primary concern of mediating between science and practice embodies the general aim .... One can say and hope that future meetings in the field of photogrammetry and its related disciplines continue to devote themselves to this task with engagement and success.“

Participants: 1909-1913: 32
1973-1985: 240

Congratulations!
Development of digital photogrammetry

Early 80s: Paradigm change “From Analytical to Digital”
Requires “fore-runner technology”:
+ Sensors ☹️
+ Computing platforms ☹️
+ Software (lacking)

Contents
- The early years (1970-1984)
- First systems and experiences (1984-1988)
- Fully digital era (2000-now)
The Future?
“I never think of the future. It comes soon enough.”
Albert Einstein

Safe prediction:
Sensors: Smaller, Processing: Faster, Results: Better(?)

The Foundations

1964 - 1980: Image processing algorithms
1972 - 1980: Network aspects (syst. errors, blunders; reliability)
1980 - 1984: On-line triangulation by sequential estimation (Kalman, TFU, Givens)
1980 - 1984: Charge Coupled Devices (CCD) and applications
   Butted Linear Array CCDs with 10 000 elements in a row
   Framegrabbers, Workstations (Tektronix, Sun)
   Image processing systems with data acquisition devices
1984: L.S. image and template matching (algorithmic basis)
The early years (1970 – 1984)

1972 Landsat 1, NASA, Satellite remote sensing
1976 13th Congress of ISP, Helsinki
  7 Analytical Plotters, Analogue → Analytical
1979 Mapsat (Colvocoresses, epipolar principle, along track)
1980 14th Congress of ISP, Hamburg, ISP → ISPRS
1981 Stereosat (Welch&Marko, along track image triplet)
1982 DPS (Hofmann, image triplet)
1984 15th Congress of ISPRS, Rio de Janeiro
  > Introduction of digital close-range photogrammetry (CCD cameras)
1986 Launch of SPOT-1 (22 Feb)

Early developments in close-range photogrammetry

1974 Woltring: Human motion studies with PSD → Vicon system
1976 ISP Congress Helsinki: RTP awareness
1978 Pinkney/Kratky: On-line 30Hz vidicon, resection
  (Space Shuttle manipulator arm)
1981 Reece: SELSPOT based research (DLT, commercial)
1983 Real: Matrix camera with digital image processing in
  photogrammetric applications
1983 El-Hakim: Photogrammetric robot vision
1984 Haggren, ISPRS Congress Rio de Janeiro:
  New vistas for industrial photogrammetry
Pinkney, Kratky, NRC, 1978: Docking maneuver for Space Shuttle Manipulator arm

Fully digital systems

H. Haggren, Rio de Janeiro 1984: "The present low pixel resolution has to be cracked in some way."

HUT prototyp system:
2 video cameras, special processing modules
128x128 pi, 4 bits
Accuracy: 1 : 500 – 1 : 1000

Mapvision
“Digital Plotters”


- 1985 “DIPS” Digital Station at IGP, ETH Zurich
  KONTRON IPS 68K
  2 CCD frame transfer cameras AQUA TV (384x576, 604x576 pixels)

- 1986 ISPRS Commission II Symposium, Baltimore, Maryland
  Phot. and Remote Sensing Systems for Data Processing and Analysis

Hardware architecture of a Digital Station
DMA specifications for DSCC
- Processing of stereopair; automatically, operator-controlled
- Photometric processing
- Per photo: 20'000 x 20'000 pi
- Radiometric resolution: 8 bits
- Roam Rate: 2.5 mm/Sek (200 pi/sec)
- Fast model traversing:
  Establishment of stereomodel \( \leq 2 \) sec
- DHM data generation: 200 pts/sec
- DHM matching accuracy: 1 pi/image
- Superposition („Video Map“)
  planimetric elements, elevation data; flicker mode
- Generation of local image patches (feature points)
  (objects, control points, tie points)

First systems and experiences (1984 -1988)

1985 Burner et al.: Calibration of vidicon tubes
  Real, Fujimoto: CCD-based stereo system
  Hobrough, Hobrough: STEREOPSIS system ("videogrammetry")


1986 El-Hakim: CCD-Stereo system based on IRI-D 256
  Wong, Ho: 2 GE TN250 CID cameras (toy moose)
  Murai et al.: 2 linear array CCDs (2048 pi), structured light
  Haggren: MAPVISION, 4 CCD cameras, synchronization,
  targetted object points, 1 sec per point

1986 Gruen, Beyer: 4 CCD cameras, Kontron IPS 68K,
  non-simultaneous, 2D testfield

1987 Gruen, Beyer, Dähler: DIPS II, Sun, Datacube boards,
  3D testfield, systematic errors
Problems with video signal

Difference of line jitter in fields leads to displacement between lines.

Line jitter shown for an image grabbed from a video recorder.

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Precision and Accuracy

<table>
<thead>
<tr>
<th>Application</th>
<th>Precision / Accuracy</th>
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<tbody>
<tr>
<td>Internal Stability</td>
<td>0.005 Pixel (30 - 40 nm!)</td>
</tr>
<tr>
<td>3-D laboratory conditions</td>
<td>0.02 Pixel</td>
</tr>
<tr>
<td></td>
<td>1 : 40 000 accuracy</td>
</tr>
<tr>
<td></td>
<td>1 : 70 000 precision</td>
</tr>
<tr>
<td>3-D industrial conditions</td>
<td>0.1 Pixel and better</td>
</tr>
<tr>
<td></td>
<td>1 : 10 000 and better</td>
</tr>
<tr>
<td>Speed: 20 msec up to several minutes</td>
<td></td>
</tr>
</tbody>
</table>
Table Tennis Robot 1988
DAGM Zurich Winner, World Champion Singapore

Trajectory: Timing

- Speed of ball: 5 m/sec
- Positions: 18
- Time for Reaction = 340 msec

Development of sensors

*Terrestrial Photogrammetry*

1986  Canon CI 10 + JVC Monitor  0.4 Mpi  SFr 5 500
1986  Canon RC 701 SLR + player/rec.  0.2 Mpi  SFr 11 200

**PhoWo 14-19 Sept. 1987:** Towards Real-Time Photogrammetry

1989  Kontron  ProgRes 3000  7.5 Mpi, 8 sec/image, SFr 50 000 + 22 000
1993  Kodak DCS 200  1.5 Mpi  SFr 16 000

**Today:** Hasselblad & Phase One back  39 Mpi, 2 sec/image  
ca. SFr 40 000
Development of digital photogrammetry

ISPRS Commission II Symposium Rovaniemi, July 1986: “From Analytical to Digital”

ISPRS Intercommission Conference on “Fast processing of photogrammetric data”, Interlaken, 2-4 June 1987:
First conference fully devoted to digital techniques
- HW for Machine Vision systems (Kontron Bildanalyse GmbH)
- Transputer Arrays for real-time feature matching
- Image acquisition, image quality, calibration of video cameras
- Digital processing of SPOT imagery
- On-line triangulation
- Image matching: Multi-image, Facets stereo (FAST) vision
- Automatic DTM generation on Kern DRS-11
- Förstner Operator
- Mapvision system, DCCS (Helava)
- Digital ortho-images, array algebra

Panel Discussion: “Digital Photogrammetry – Quo Vadis?”
PhoWo 2009: ”Future of Photogrammetry”

K. Atkinson, ISPRS Kyoto 1988:

“The Kyoto Congress saw Commission V, once the ugly sister of ISP, emerge as one of the stars of the show.”
Acceptance and refinement (1988-1994)

- Calibration operational
- Digital aerial cameras (medium format)
- High accuracy measurement algorithms/systems
- Fully digital automated systems
- Digital ortho-images
- CAD interface/integration, visualization
- Diversity of applications
- Industrial photogrammetry established
- Few robotic and medical applications

PTV measurements

Software: Free web download, 45 lic. per year
27/28 August 2009: COST Conference, ETH Zurich
Development of digital systems
Without scientific basis

ISPRS Conference on “Digital Photogrammetric Systems”,
4-6 September 1991, TU Munich:
Session “Design Research” – user interface, data transfer,
image handling, measurement techniques
(design no scientific basis, on-the-job experimentation)
What automatic – what semi-automatic?

3 stages of an innovative product
1. Technical solution
2. Acceptance by customer
3. Strategic instrument in the market

Technology – too early/too late?
„The citizen’s problem, at bottom, is how to assess
the things that so often come forth in the beguiling
guise of blessings.“

Wirz: Marginalien zur Werbung. Werd Verlag, Zürich, 1989
Digital Workstations
On the ISPRS agenda: Since 1986
(Symposium Comm. II, Baltimore)

Kern & Co., ISPRS Congress
Kyoto 1988:
„We yodel digitally“

ISPRS Symposium Zürich, Sept. 1990:
“Close-Range Photogrammetry Meets
Machine Vision”

WG V/6: Biostereometrics and Medical Imaging

- **Applications:** Face, eye, dentistry, heart, lung, knee, hip-joint, respiration, body surface, motion (human, animal), sports

- **Sensors:** CT, SEM, MRI, X-ray stereo, REM stereo, laser scanning microscopy, tomography, radiography, ultrasound, CCDs

1989: Comm.V
WG chairmen in Lagna

- Large format digital aerial cameras, LiDAR
- Feature and object extraction (city models, road extraction)
- 1998: 15 commercial digital stations with 3D capabilities
- Image matching for DSM generation

- Highres satellite sensors: IKONOS, etc.

- Terrestrial photogrammetry:
  + High accuracy (1:10 000 to 1:100 000), industrial/eng. applications
  + Fast processing, image sequences (robotics, motion analysis, PTV)
  + Surface measurements, large structures;
    laser-scanners, structured light systems
  1998: 27 commercial systems for surface reconstruction
  16 body scanners and 7 face trackers
  + Mobile Mapping, multi-sensor concepts
  1999: 10 road-based MM systems

ISPRS Congress Vienna 1996 – Comm.V topics

- **Architectural Photogrammetry**
  - photographic/hybrid: 21
  - digital (CCDs): 11

- **Industrial applications**
  - photographic/hybrid: 3
  - digital (CCDs): 20

- Moving objects: 7
- Moving sensors: 1
- Calibration: 3
- Depth-from-focus: 1
- Network design: 1
- On-line triangulation: 1
- Size of targets: 1
- Matching: 2
- Meas. algorithms/accuracy: 1
- Orientation without CPs: 1
- Spatial resection, closed form: 1
- Mikroscopy: 3
Al Gore, Vicepresident USA, January 1998:
The Digital Earth: Understanding our planet in the 21 century
“I believe we need a ‘Digital Earth’: a multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data.”

- Digital Earth Society (Beijing)
- Google Earth
- Microsoft Virtual World, etc.


19th ISPRS Congress, Amsterdam 2000: ADS40

Highres satellite imaging (within 10 years: footprint improved by factor 10)

PhoWo 2003:
Ubiquitous computing
Analogue vs. digital image data collection (cameras: DMC, UltraCam)
IKONOS, Quickbird
LiDAR DEM
Distributed photogrammetric data analysis: Automated AT, integration of sensors (GPS/INS), Pixel Factory
3D visualization and animation (city models, buildings outside and inside)
Space activities

ESA-ESTEC: Planck, Herschel, Gaia, 1:1 Mill.

NASA’s Rover SPIRIT

Moon Explorer
SELENE; JAXA

China’s Chang’e-1

Development of satellite sensors

1972 Landsat MSS 80 m GSD
1986 SPOT stereo 10 m
2001 Quickbird stereo 0.6 m

Within 35 years: > Factor 150 in resolution

10.2007: WorldView-1 0.5 m
1.7 days revisit
10.2008: GeoEye -1 0.5 m
HRSI Processing: Summary

Georeferencing
• For IKONOS, Quickbird and SPOT-5 bias-corrected RPCs & rigorous models with same results: planimetry: 0.3 pi height: 0.5 pi
• For ALOS/PRISM and Cartosat-1: planimetry: 0.5 - 0.8 pi height: 0.3 - 0.8 pi
  Sufficient for conventional mapping 1: 10 000

DSM generation
• Accuracy (along track): 1-5 pi depending on terrain slope and land cover
• ALOS/PRISM: 2 – 3 pi
• Cartosat: 1 - 3 pi
• But still many large bunders Not ready for mapping 1: 50 000!
• DSM > DTM reduction not solved yet

Radiometric Quality

Zurich aerial

PRISM Zurich
Aerial Sensing

Optical digital cameras (large/medium, oblique)
Laserscanners (LiDAR), GPS/INS
Radar, InSAR

Multiple camera heads
New trend: Oblique imaging
Photogrammetry and Remote Sensing:
Turning images into n-dim models (+ semantic info)

Example: Firenze

A REAL-TIME PHOTOGRAMMETRIC MAPPING SYSTEM, Sherman Wu et al.

One-Path Photogrammetric Program (OPPP): Processes automatically DEM, ortho-images, and contour lines onboard and in real-time.

Figure 3. RTPMS general processing flow.
Development of close-range sensors

Low cost cameras
Panoramic cameras
Laserscanners, structured light
3D CCD/CMOS chips
Hybrid systems

Large format cameras:
Hasselblad&Phase One:
39 Mpi, 2 sec/image, ca. SFr 40 000

Mobile (Ubiquitous) Photogrammetry

Example: Sony Ericsson K750, 2Mpi camera,
bluetooth, UBS, etc.

Ricoh 500SE
GPS-ready Digital Camera
Capture Location Data with Your Images

Find Resellers
Download Brochure
View the Quicktour

5 Mpi Kamera
video 30 f/sec
GPS
8 Gbyte Speicher
Cultural Heritage

Weary Herakles

Alfred Escher

Petroglyphs in Chichictara

St. Gallen Globus

Bamiyan Buddha

Fast 3D modeling – Templo los Macarones, Campeche, Mexico

Some of the original frames (total 6 images, 1856x1392)
Object dimensions: 3 x 1.5 m

Recovered camera poses

Shaded 3D model
(2M points and 20 000 edges)

Textured 3D model
Breuckmann optoTOP-HE system
- Accuracy ca. 50 microns
- 1.5 days with 67 scans
- Each scan 1.3M points
Multi-sensor approaches
Project St. Gallen Globe Replika

Data acquisition:
ca. 460 Scans with stripe projector and
data 250 + 2000 images with digital cameras

Data processing:
Object-accuracy ~0.8 mm

St. Gallen Globe Replika, 3D model

Hybrid (textured) model

Wireframe model
Analysis of Interior by X-Rays

- X-rays to analyse the interior of the Globe (construction of axis, materials)
- Performed by EMPA (Annex Institute of ETH Zurich for Material Science)

Axis and metal parts

Material behind the globe surface

Use of hybrid systems: Laserscans and images

3D city modeling: 3D LANDMARKS for car navigation

Courtesy CyberCity AG
3D city modeling: 3D LANDMARKS for car navigation

Courtesy CyberCity AG

Forum Pompeji –
3D Modeling of complex site using multi-sensor, multi-resolution approaches

+ Dept. INDACO, Politecnico of Milano, Italy
+ Institute of Geodesy and Photogrammetry - ETH Zurich, Switzerland
+ Centre for Scientific and Technol. Research – B. Kessler Foundation, Trento, Italy
+ Dept. of Applied Sciences, Parthenope University, Naples, Italy
## Used technologies and multi-resolution data

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Use</th>
<th>Quantity</th>
<th>Geometric resolution</th>
<th>Texture resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerial images</strong></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Zeiss RMK A 30/23</td>
<td>DSM of the site at low</td>
<td>3</td>
<td>25 cm</td>
<td>5 cm</td>
</tr>
<tr>
<td></td>
<td>resolution</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pictometry</td>
<td>Texturing</td>
<td>4</td>
<td>-</td>
<td>15 cm</td>
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<tr>
<td><strong>Range sensors</strong></td>
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<tr>
<td>Leica HDS3000</td>
<td>Modeling of entire Forum at</td>
<td>21 scans</td>
<td>5-20 mm</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>middle resolution</td>
<td></td>
<td></td>
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<tr>
<td>Leica HDS6000</td>
<td></td>
<td>45 scans</td>
<td>5-10 mm</td>
<td>-</td>
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<tr>
<td><strong>Terrestrial images</strong></td>
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<tr>
<td>Canon 10D</td>
<td>Modeling of small finds,</td>
<td>&gt; 3000</td>
<td>0.5-10 mm</td>
<td>0.2-5 mm</td>
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<tr>
<td>(24 mm lens, 6 Mpixel)</td>
<td>mural architectural</td>
<td></td>
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<tr>
<td>Canon 20D</td>
<td>structures, ornaments</td>
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<tr>
<td>(20 mm lens, 8 Mpixel)</td>
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<tr>
<td>Kodak DCS Pro</td>
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<tr>
<td>(50 mm lens, 12 Mpixel)</td>
<td></td>
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<tr>
<td>Nikon D300</td>
<td></td>
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<tr>
<td>(20 mm lens, 12 MPixel)</td>
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### High resolution: Photogrammetry with interactive modeling

- Over 3000 images acquired
- Bundle block-adjustment
- Interactive modeling to define the main geometric entities
- Geometric resolution (footprint): 0.5-10 mm
The Sacred Mountain in Social Context: Symbolism and History in Maya Architecture—Temple 22, Copan Honduras
"TEMPLE 22" is known as the "Parthenon of the Maya world" because its remarkable sculpture is in museums around the world.

A NEW VISION OF TEMPLE 22 EXISTS, BUT HOW TO EXPLAIN THIS COMPLEXITY OTHER THAN IN 2D DRAWINGS?

THE ANSWER:

- reality-based 3D model and reconstruction of Temple 22, East Court and Principal Group, at varying levels of detail.

METHODS:

1. Photogrammetry and laserscanning of architecture and sculpture on site, and in warehouses and museums via photogrammetry and structured light for reality-based reconstruction.

2. CAD integration and VR simulations for the reconstructed portions.

3. Develop 3D GIS website for online download and viewing of the model (among other things).
UAV photogrammetry (Palpa/Nasca, Peru)

Student project: Castle Landenberg

Symbol of Obwalden in the Swiss passport
Landenberg: Flight planning

- Circle with a radius of 25 meters
- 24 images; every 15°
- Images oblique
- Simulation

Student project: Castle Landenberg
Aeroscout Scout B1-110 with aerial laser scanner

New Motion Capture standards

**Vicon**: MX 20+ Motion Capture Camera, Markers
- 2 Mill. pi, 166 frames/sec, 10 bit
- MX Ultranet: 245 cameras simultaneously

**Movie Troy** (Prad Pitt):
- 555 shots, up to 5 performers simult.
- 3 hrs MOCAP data
Motion Analysis

The Return of the King: 18 000 virtual effects shots
3 500 Linux-based processors
420 people (Weta Digital, Wellington)

Gollum: MoCap, roto-motion, keyframe animation
16 cameras à 1.3 Mpi, 60/120 fr/sec
10 people MoCap, 15 people MoEdit

3D movies (+ TV channel BSkyB, 2010)

Steven Spielberg (TA 4.7.09) on the revolution of the 3D film:
“ I find it fascinating how 3D images resemble real life; we also see reality three-dimensionally”
Geogames

- DTM and satellite/aerial images

Microsoft Flight Simulator X

- DTM and train-track data

Microsoft Train Simulator 2

Geogames

- Laserscan to obtain race track geometry

iracing.com – motorsport simulations

- Motion capture to animate (laser scanned) model

NHL 2k9 – images by cnet.com
Photogrammetry – a secret technology?

„As a scientist I had a unique opportunity. During my time astronomy reached the market places.“

Galileo Galilei to Andrea Sarti in „The Life of Galilei“, by Bertold Brecht

The Market Place

2.2009: Teleatlas maps Thailand
3.2009: GeoEye-1 for Google Earth
8.2009: WorldView-2 arrives at Vandenberg Air Force Base, Launch 6.10.09

28/05/2009: RapidEye Constellation's 100 Days
RapidEye have collected more than 69 Million square kilometres of at least 80% cloud-free images during their first 100 days of operation. The imaging campaigns were concentrated in Europe, the U.S., Brazil and China. More than 36 Million square kilometres of the Earth's surface, or about one quarter of the total landmass were imaged, often several times.
28/05/2009: 3D Models of European Cities
Blom has completed the production of the first 40 high quality 3D models, Blom3D, of European cities. The Blom3D models have been delivered to Tele Atlas for integration into navigation, LBS and mapping solutions. Tele Atlas has already announced that they have launched the photorealistic buildings and blocks created by Blom, as part of their navigation solutions. Their solution, named Advanced City Models, will enhance the user-experience of any navigator integrating the solution.

01/06/2009: Large-Scale Mapping for UK
The GeoInformation Group has launched a new mapping programme. UKMap is the UK's first commercially funded, large-scale topographic mapping and address database created completely independently of the Ordnance Survey.

Employing more than 100 people across three continents, UKMap is a five-year programme to map over 500 towns and cities covering all urban areas with a population greater than 10,000 - some 24,000 square kilometres throughout the UK. London is the first complete UKMap city with over 1,700 sqkm and will be available on 1 Sept 2009.

Geo-enabling Mobile Phones (navigation, maps, 3D models, …)
O.-P. Kallasvuois, President&CEO Nokia, 4.2009: “We have focused our investments on five primary categories: maps, music, messaging, media and games.”
Changes in society & economy

- New environments for R&D, Education and Professional Practice
  - New interest in geosciences
    - Natural and man-made hazards
  - Communication
    - Technology & knowledge transfer, data accessibility
  - Globalization of science
  - Diversification, interdisciplinarity
    - Technology and applications

Impact on profession

(a) Inflation of data

"An image is worth a thousand words" – What will 100 Mill. images tell us?

Ubiquitous imaging, Cloud-based Computing

Processing capabilities trailing behind data acquisition rate

- ETHZ: Center for Imaging Sciences & Technologies
  - Google, Microsoft street images: Transparent human, personality issues

(b) Increased system complexity

- More blackboxes or better/more education?

(c) Competition from neighbouring disciplines

- Development of own capabilities and attitudes
  - (openness, flexibility, self-assurance)
- Maintain depth in research
Mission mit Sollbruchstelle
Die Nasa will eine Sonde auf den Mond abstürzen lassen


Der LRO wird den Himmelskörper in 50 Kilometer Höhe umkreisen. „Wir müssen uns besser mit den Landschaften des Monides vertraut machen, mit seinen Bergen und Tälern, um künftige Landeorte gezielt auszuwählen zu können“, sagt Scott

Weg frei für Google
Datenschützer gestatten Street View

Photogrammetry today:

+ From point positioning and 2.5D mapping to an integrated, unified n-D technology, encompassing satellite, aerial and terrestrial sensor platforms
+ From single sensor/multiple processing instruments to multiple sensors/single processing platform technique

(1) Technologies are converging (satellite, aerial, terrestrial)
Processing (almost) platform-independent

(2) Image understanding is a hard problem
Full automation only possible for highly structured images or unstructured products
Remedy: Multi (hybrid)-data approach (?)

Image-, scene understanding

Rodney Brooks, MIT (The Road to 2030 - A Wild Ride), 2005:
” (For navigation) The robots of tomorrow will need to have the object recognition capabilities of a 2-year old child,…”

Measurement or modeling errors ??
Do not forget:

Photogrammetric principles/priorities

* Sophisticated sensor models, network competence
* Refined measurement algorithms (→ precision)
* Redundant data (→ reliability)
* Self-diagnosis, quality control
* System design for general applicability
* Engineering approach: Testing, validation, robustification

Service to profession!

The Future

Al Gore, Vicepresident USA, January 1998:

„Working together, we can help solve many of the most pressing problems facing our society, inspiring our children to learn more about the world around them, and accelerate the growth of a multi-billion dollar industry.“