PHOTOGRAMMETRY FOR NATURAL AND CULTURAL HERITAGE SITE DOCUMENTATION, MAPPING AND VISUALIZATION

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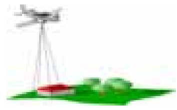

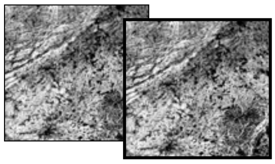

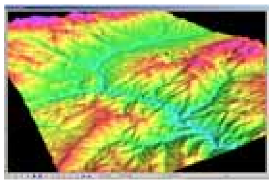

PART 1

<u>with contributions from:</u>
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Contents

- Instruments (cameras, sensors, platforms)
- Requirements
- Products (DTM, Orthophotos, Maps, 3D Models)
- Related 3D technologies
- Applications (documentation, mapping, visualization, GIS, maintenance, reconstruction, …)
- Photogrammetric modeling pipeline
- Software
- From 2D data to 3D model and GIS: The Bamiyan project example
- Examples: Bamiyan, Nasca, Machu Picchu, Angkor Wat, Tucume, Everest

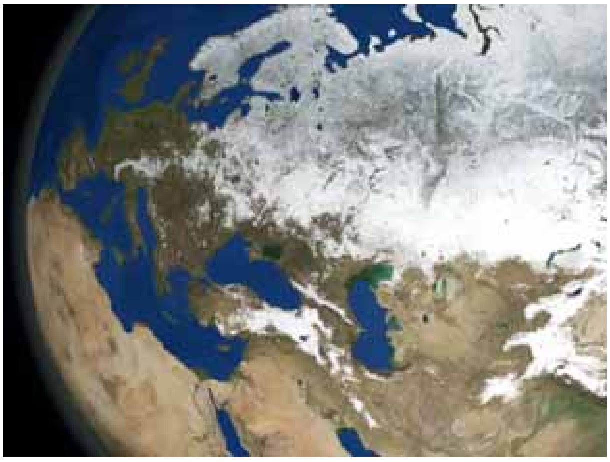
Photogrammetry?

Remote Sensing?

Satellite data?

3D Modeling?

Digital Terrain model?



Photogrammetry?

→ The science of obtaining reliable measurements by means of photographs / images

→ The art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting photographic images and pattern of electromagnetic radiant energy and other phenomena

→ The art of turning images into 3D models

Photogrammetry: Analogue ➡ Analytical ➡ Digital

Remote Sensing, Computer Vision

INPUT:
- Satellite images
- Analog aerial-photos
- Digital airborne images
- Terrestrial images (digital/analog)
- GPS data
- ...

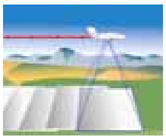
→

OUTPUT:
- Digital Terrain/Surface Models (DTM, DSM)
- Ortho-images
- Maps
- (Textured) 3D models
- GIS layers
- ...

Photogrammetry with ...

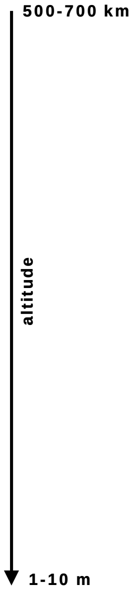
+ spaceborne (optical) images

+ aerial images



+ helicopter / baloon images

+ terrestrial images



Photogrammetry & Images

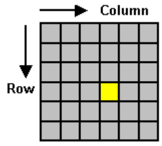
Digital images vs analogue photos

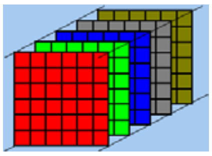
Digital data

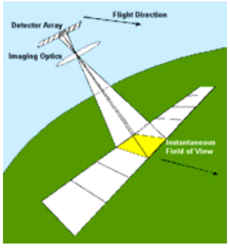
• Pixel:
- Smallest element of a digital image
- Pixel size = dimension of each element (e.g. 4 micron)

• Spatial resolution:
- Number of pixel used in a digital image
- Spatial resolution increases if the pixel size decrease
- Resolution in image space vs resolution in object space (foot-print or GSD)

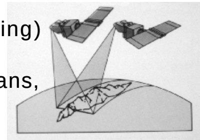
• Sensor:
- Hardware component constituted of detectors producing images







Satellite Photogrammetry (Remote Sensing)

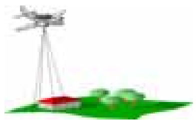


Photogrammetry: extraction of metric information from images (ex. mapping)

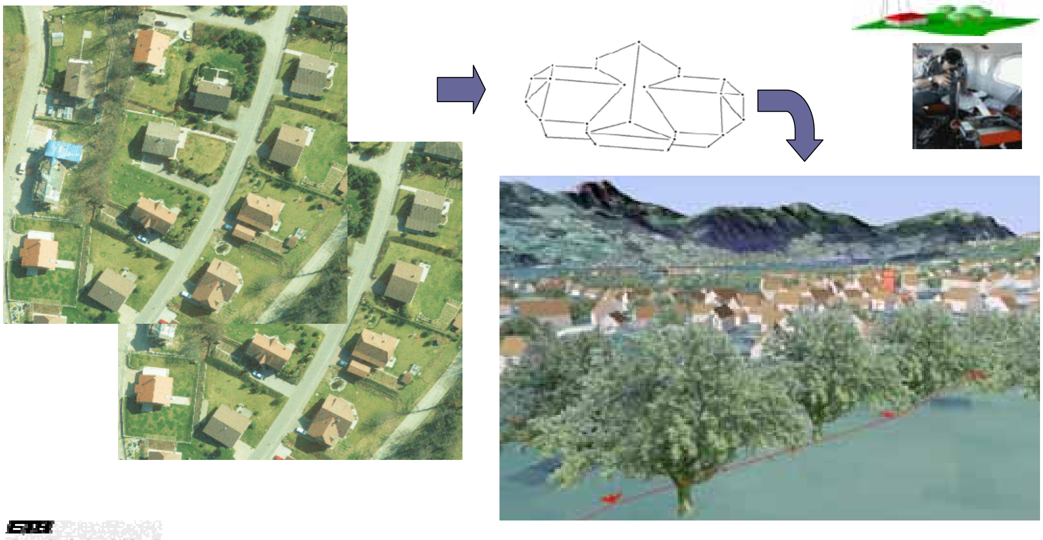
Remote Sensing: analysis of land (ex. land use or vegetation studies) oceans, atmosphere, temporal changes etc.

Quickbird image over Torino (ca 500 km altitude)

Aerial Photogrammetry - airplane



Classical photogrammetry, for map production, DTM generation, etc.



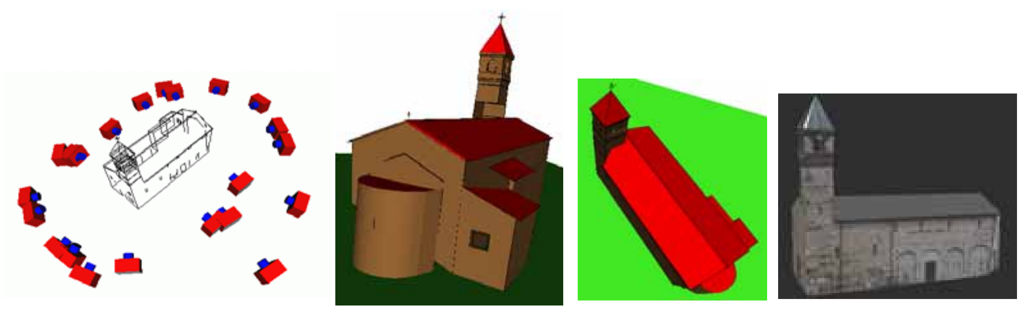
Aerial Photogrammetry - helicopter

New trend: Unmanned Autonomous Vehicle (UAV)

[Helicam, WeControl]

Close-Range (Terrestrial) Photogrammetry

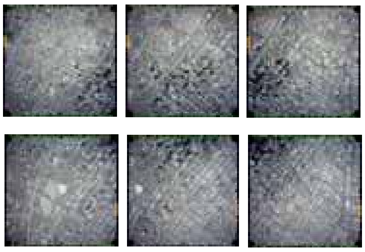
3D modeling of terrestrial objects

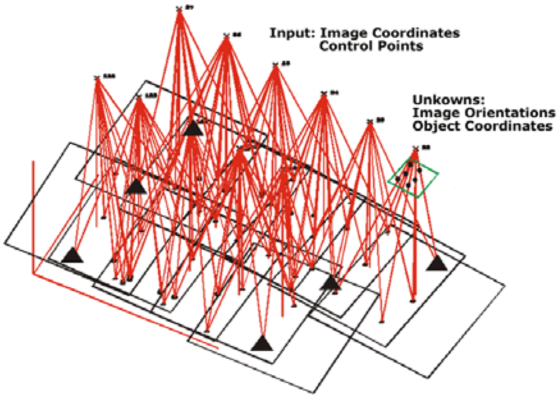


Photogrammetric Principle: how does it work?

- Space intersection of rays passing through homologous points in multiple images
- At least 2 images / photos
- Generation of 3D coordinates (object) from 2D coordinates (image)

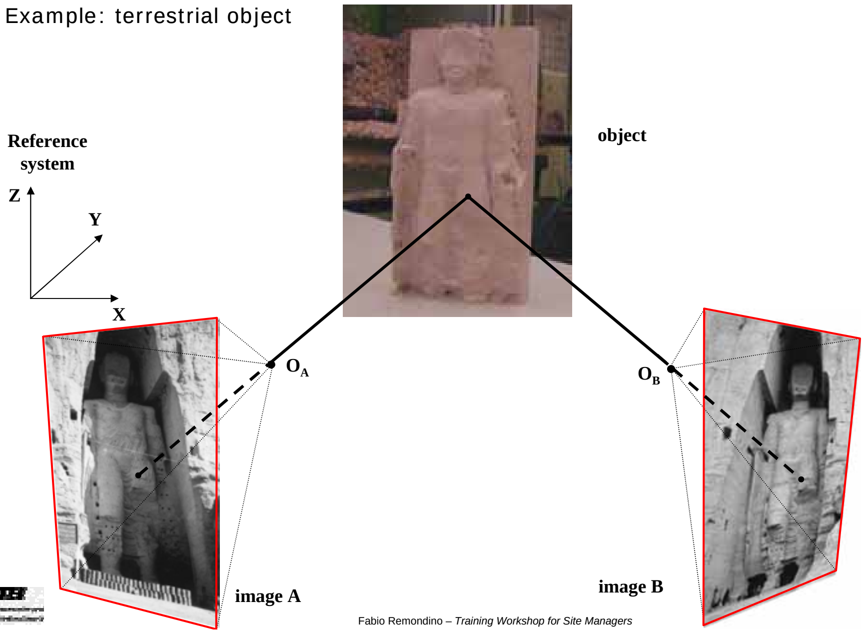
- Example: aerial block





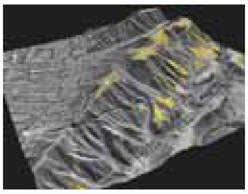
Photogrammetric Principle: how does it work?

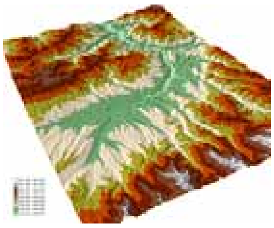
- Example: terrestrial object



Photogrammetric Requirements

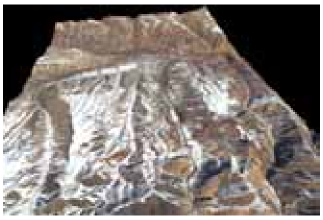
- High geometric accuracy
- Complete details
- (Automation)
- Photo-realism
- Low cost
- Portability
- Flexibility





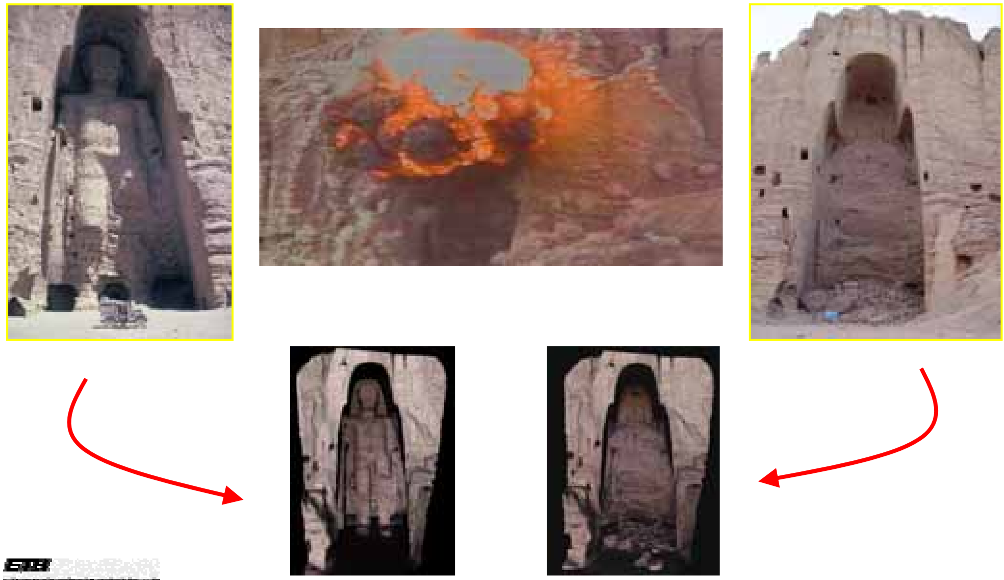
Photogrammetric Produts

- Digital Terrain Models (DTM)
- Orthophotos
- 3D Models
- Maps
- ...



Photogrammetric Products: 3D Modeling

Before March 2001 | March 2001 | After March 2001



Photogrammetric Products: 3D city models

San Francisco in GoogleEarth

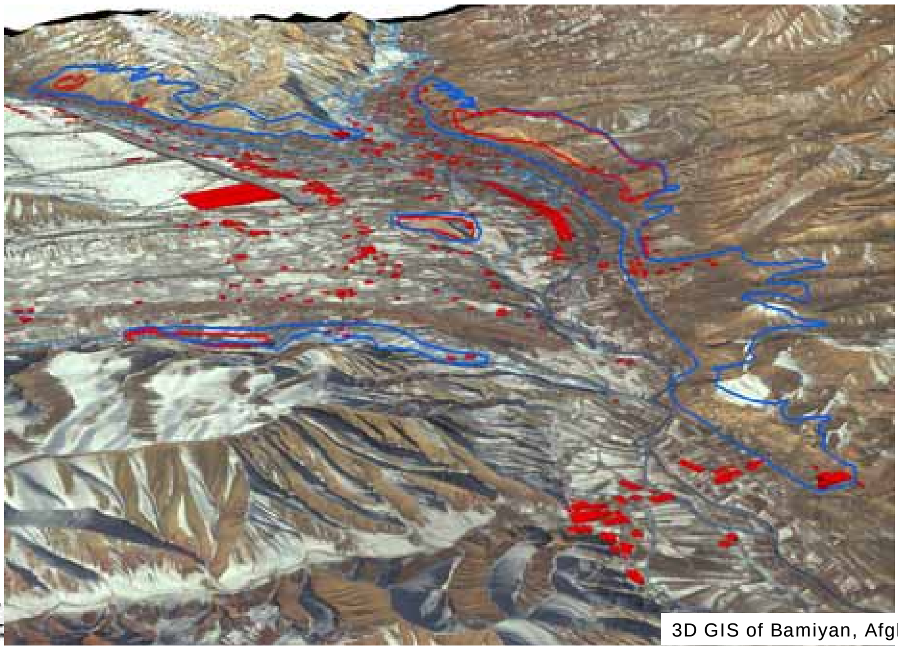
Los Angeles Downtown, by CyberCity AG

Photogrammetric Products: 3D city modeling and planning

3D city modeling

3D city planning

Photogrammetric Products: 3D GIS



3D GIS of Bamiyan, Afghanistan

Photogrammetric Products: Documentation

- Documentation with panoramic images

e.g. http://www.world-heritage-tour.org/

Bamiyan Cliff, Afghanistan

- Empty Niche of the Great Buddha

Angkor Wat, Cambodia

Machu Picchu, Peru

3D Technology

- Image-based technique: *Photogrammetry*

(3D) measurements from images
- Time consuming
+ 3D and texture from the images
+ Results independent from the scene/object
+ Low costs
- Possible smooth effects on small details

• Triangulation principle (at least 2 images)

- Range-based technique: *Active Sensors*

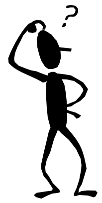
Sensors which provide directly 3D info
- High costs
- Usually no texture
- Results depend on the type/quality of surface
+ Very fast acquisition
+ Able to acquire all the small details

• Triangulation or time delay principle

- Surveying & CAD tools

3D Technology selection

- We *usually* need some surveying steps *(scale, georeferencing)*
- The choice is less obvious between image- and range-based (project requirements, budget, object type/size, etc.)



- Budget?
- Requirements?
- Project size?
- Which image-based method to use ?
- Which laser scanner to use ?
- What parameters and configurations to select ?

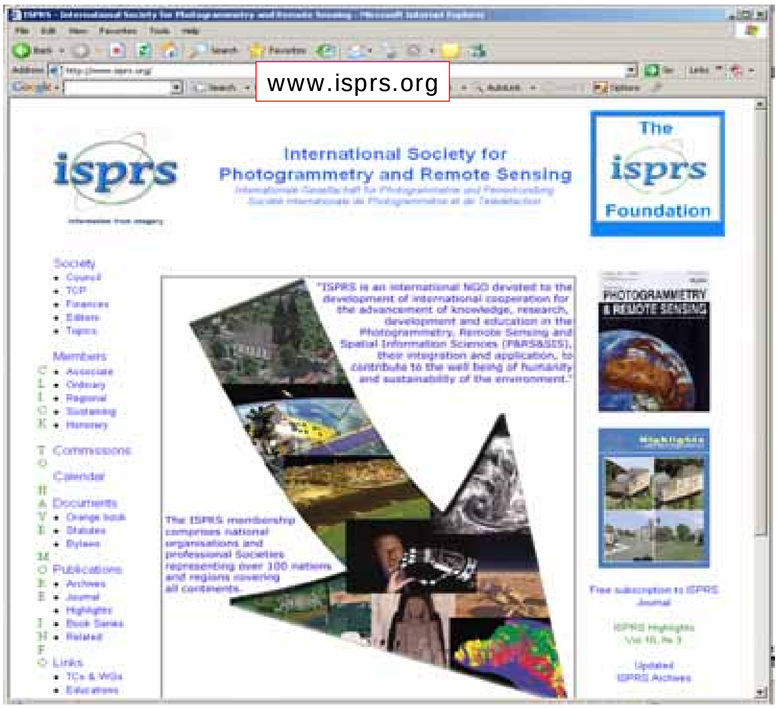
Image-based approach
(Photogrammetry)

Photogrammetric Applications

- Documentation
- Cartography
- Animations & Visualization
- GIS
- City Planning
- Industrial measurements
- ...

For Natural & Cultural Heritage Sites:

- Documentation in case of loss or damage
- Education resources
- Interaction without risk of damage
- Virtual tourism and virtual museums
- Maintenance
- Physical reconstruction
- ...

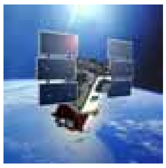


Instruments: Cameras, Sensors, Platforms

- Sensor type
  - Passive
    - Non-imaging
      - Microwave radiometer
      - Magnetic sensor
      - Gravimeter
      - Fourier spectrometer
      - Others
    - Imaging
      - Optical
        - Film-based
        - **Digital**
          - Point-based
          - **Linear array**
          - Frame
      - Non-optical
        - Microwave radiometer
  - Active
    - Non-imaging
      - Microwave altimeter
      - Microwave radiometer
      - Laser water depth meter
      - Laser distance meter
    - Imaging
      - Optical
        - Hybrid systems (I.e. laser+ frame sensor)
      - Non-optical
        - Phased array radar
        - Read aperture radar
        - Synthetic aperture radar

Photogrammetry with …

+ (optical) spaceborne images



+ aerial images

+ helicopter / baloon images

+ terrestrial images

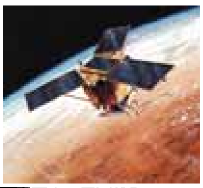
500-700 km

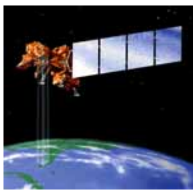
altitude

1-10 m

Spaceborne systems

+ Great variety of platforms providing images at different resolution (GSD up to 0.7 m/px)
+ High quality and high dynamic range images
+ Suitable for state/provincial and national level mapping (up to 1:20,000)
+ High and almost instant availability all over the world
+ Relatively high positioning accuracy
+ Along-/cross-track stereo imagery acquisition
- Cloud cover
- High costs
+ Different software available to handle the data
+ Continuous acquisition of images <u>or</u> on user's request





Spaceborne systems

Mission or Satellite	Ikonos-2	Quickbird-2	Orbview-3	SPOT 5	IRS-P5 (Cartosat-1)	FormoSat-2 (formerly ROCSat-2)	EROS A1	Cosmos [1], many missions	Corona (KH-1 to KH-4), many missions	KH-7, many missions
Sensor	OSA	BHRC60	OHRIS	HRG, HRS	2 PAN cameras	RSI	PIC	KVR 1000 panoramic camera (2 working alternatively)	Stereo panoramic cameras	High Resolution Surveillance Camera
Country	USA	USA	USA	France, Belgium, Sweden	India	Taiwan	Israel	Russia	USA	USA
System type	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Military, declassified	Military, declassified
Launch date or duration	9/1999	10/2001	6/2003	5/2002	5/2005	5/2004	12/2000	1981-2000	1960-1972	1963-1967
Sensor type	digital	digital	digital	digital	digital	digital	digital	film	film	film
PAN GSD (m) (across x along track)	1	0.61	1	5 or 2.5-3 (oversampled) HRG 10 x 5 HRS	2.5	2	1.9 1 or 1.4 (oversampled)	2	2-140	At nadir down to 0.45-0.5
PAN Pixels of line CCD / Pixel spacing (μm)	13,816 / 12	27,568 / 12	8,000 / 6 x 5.4, unknown if numbers here for staggered or not	12,000 (2 lines for HRG) / 6.5	12,288 / 7	12,000 / 6.5	7,043 (2 lines) / ca. 13	NA	NA	NA
Flying height (km), Focal length (m)	681, 10	450, 8.832	470, 2.77	818-833, 1.082 HRG 0.58 HRS	618, 1.98	888, 2.896	ca. 500, 3.4	Variable (190-270), 1	Variable, 0.6069	Variable, 0.96

Spaceborne systems

Mission or Satellite	Ikonos-2	Quickbird-2	Orbview-3	SPOT 5	IRS-P5 (Cartosat-1)	FormoSat-2	EROS A1	Cosmos, many missions	Corona (KH-1 to KH-4), many missions	KH-7, many missions
No. of MS Channels / GSD (m)	4 / 4	4 / 2.44	4 / 4	(excl. Vegetation instrument) 4 / 10 and 20	0	4 / 8	0	0	0	very few color & CIR images
Stereo [2]	along-track, across-track	along-track, across-track	along-track, across-track	along-track, across-track	along-track	along-track, across-track	along-track, across-track	no stereo	along-track	few images in stereo
Swath width (km) or Image film dimensions (cm)	11	16.5	8	60 HRG, 120 HRS	30	24	14, 10 for oversampled images	18 x 72 (across)	5.54 x 75.69 (across)	22.8 x variable (across)
Field Of Regard [3] (deg)	45, up to 60 deg images shot	45	50	27 (HRG, only across track)	NA	45	45	NA	NA	NA
TDI	Y	Y	N	N	N	N	N	NA	NA	NA
Along track triplette ability	Y	?	?	N	N	?	Y	NA	N	N
Body rotation angular rate [4] (deg/sec)	up to > 1	0.5-1.1	?	NA	NA	0.4-0.75	1.8	NA	NA	NA

Spaceborne systems

Mission or Satellite	Ikonos-2	Quickbird-2	Orbview-3	SPOT 5	IRS-P5 (Cartosat-1)	FormoSat-2	EROS A1	Cosmos, many missions	Corona (KH-1 to KH-4), many missions	KH-7, many missions
FOV (deg) or film area coverage	0.93	2.12	0.97	4.13 HRG 7.7 HRS	2.49	1.54	1.5	40 x 160 km (typical)	14 x 189 (typical)	
No. of quantization bits	11	11	11	8	10	12	11	NA	NA	NA
Scale factor	68,100	51,100	170,000	762,500 HRG, 1,422,500 HRS	312,000	307,000	145,000	190,000-270,000	Variable, ca. 250,000 typical	Variable
Stereo overlap (%)	up to 100	up to 100	up to 100	up to 100	up to 100	up to 100	up to 100	6-12	up to 100	?
B/H ratio	variable	variable	variable	up to 1.1 HRG, 0.8 (40 deg.) HRS	0.62 (31 deg.)	variable	variable	NA	0.60 (30 deg.)	?

[1] Actual name is Kometa Space Mapping System, on-board of Cosmos satellites, which have been used for other purposes too.

[2] Along-track is often used as synonymous to quasi-simultaneous (QS) stereo image acquisition (time difference in the order of 1 min), while across-track as synonymous to different orbit (DO) stereo image acquisition. Later definition is wrong. Agile satellites can acquire QS stereo images across-track, while with other satellites like SPOT-5 across-track means DO stereo.

[3] The Field Of Regard is given here as +/- the numbers in the table. It is valid for all pointing directions, except for SPOT-5 where it refers only to across-track. Some satellites can acquire images with even smaller sensor elevation than the one mentioned in the table under certain restrictions (e.g. Ikonos images with 30 deg elevation have been acquired).

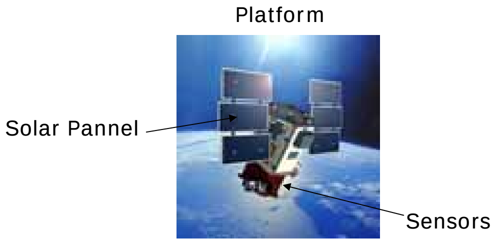
[4] The angular rate generally increases, the longer the rotation time period is.

Spaceborne systems

Satellite	Sensor	Foot-print	Swath	Spectral band						Quantisation	Availability	Stereo
Landsat 1, 2, 3, 4, 5	MSS	79 m	185 km				NIR			8 bit	since 1972	
Landsat 4, 5	TM	30/ 120 m	185 km				NIR	SWIR	TIR	8 bit	since 1982	
Landsat 7	ETM pan	15 m	183 km							8 bit		
	ETM MS	30/ 60 m					NIR	SWIR	TIR	8 bit	since 1999	
SPOT 1, 2, 3	HRV-P	10 m	60 km									x
	HRV-XS	20 m					NIR			8 bit	since 1986	x
SPOT 4	HRVIR-M	10 m	60 km									x
	HRVIR-X	20 m					NIR	SWIR				x
	Vegetation	1.15 km	2200 km				NIR	SWIR		10 bit	since 1998	
SPOT 5	PAN	2.5/ 5 m	120 km				NIR			8 bit		x
	MS	10 m	120 km				NIR			8 bit	since 2002	x
IRS 1C, IRS 1D	PAN	5.8 m	70 km							6 bit		x
	LISS II	23.5/ 70.8 m	140 km				NIR	SWIR		7 bit		
	WIFAS	188	770 km				NIR			7 bit	since 1995	
MOMS-Kamera	PAN	6 m	50 km				NIR			8 bit		
	Stereo	18 m	105 km				NIR			8 bit		x
	MS	18 m	105 km				NIR			8 bit	since 1996	
Quickbird	PAN	0.6 m	16.5 km				NIR			11 (16)		x
	MS	2.4 m	16.5 km				NIR			11 (16)	since 2001	x

Spaceborne systems

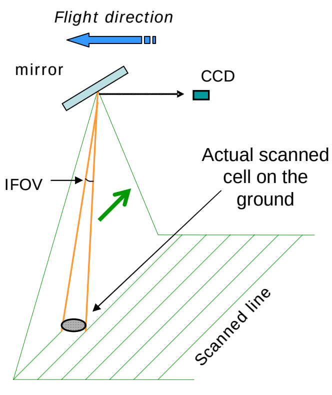
Satellite	Sensor	Foot-print	Swath	Spectral band	Quantisation	Availability	Stereo
IKONOS	PAN	1 m	11 km	NIR	11 bit		x
	MS	4 m	11 km	NR	11 bit	since 1999	x
OrbView 3	PAN	1 m	8 km	NIR	8 (12)	since 2004	
	MS	4 m	8 km	NR	8(12)		
OrbView 4 (planned)	Hyper	8 m	5 km	up tp 200 channels		soon	
RESURS-F1, MIR 1	KFA-1000	5-8 m	ca. 80 km	NIR	Film	since 1974	x
RESURS-F2	MK-4	8-12 m	ca.144 km	NR	Film	since 1987	x
KOSMOS-Serie	KVR-1000	2 m	40 km		Film	since 1984	
	TK-350	10 m	200*300 km		Film	since 1981	x
ERS 1, 2	SAR	12.5 m	100 km	RADAR	16 bit	since 1991	
JERS 1	SAR	18 m	75 km	RADAR		since 1992	
RADARSAT	SAR	ab 8 m	ab 50 km	RADAR		since 1992	



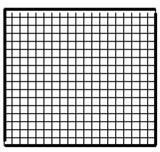
Spaceborne optical systems

Main components: Platform + Sensors + Solar Pannel

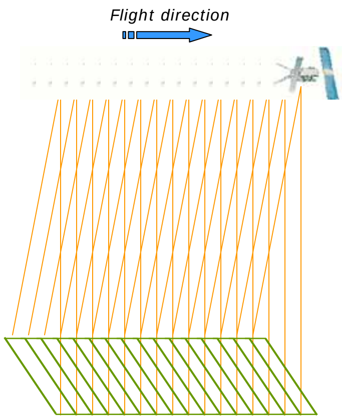
Sensors →
- CCD single sensor + mirror => Whiskbroom Scanning
- CCD frame sensors
- CCD linear sensors => Pushbroom Scanning



Whiskbroom Scanning



Frame sensor

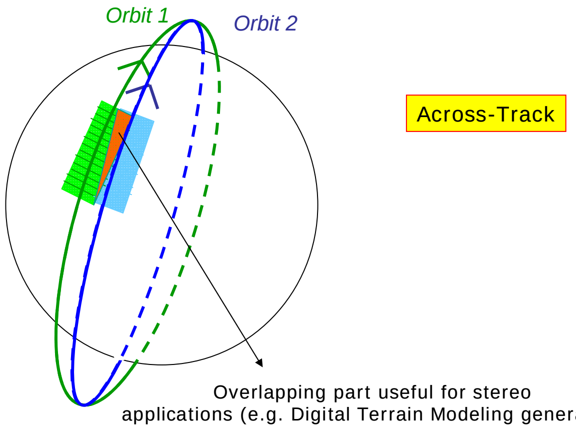


Pushbroom Scanning

Spaceborne optical systems - Stereo capabilities

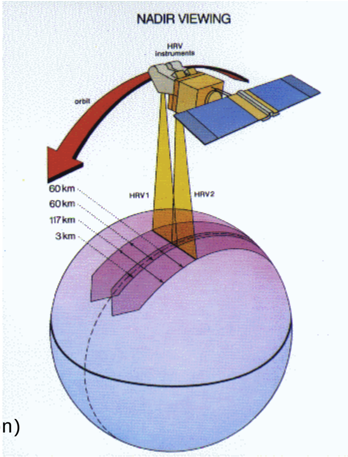
• Important for 3D analysis, mapping, etc.

In case of linear sensor:



Overlapping part useful for stereo applications (e.g. Digital Terrain Modeling generation)

Difficulties due to time gap between orbits



Spaceborne optical systems - Stereo capabilities

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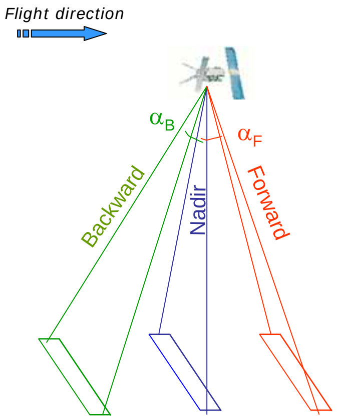
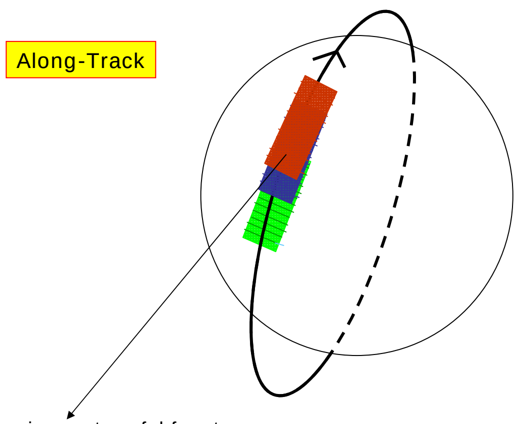
In case of (3) linear sensor:

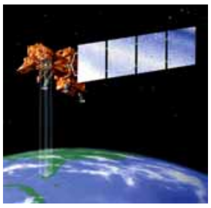


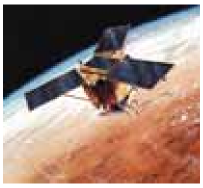


Overlapping part useful for stereo applications (e.g. Digital Terrain Modeling generation)

Spaceborne optical systems

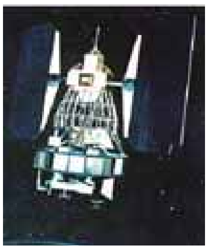
Some examples of platforms and images





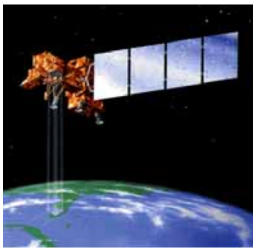
Spaceborne systems - LANDSAT

http://landsat7.usgs.gov/



Landsat 1-3

Landsat 4, 5



Landsat 6, 7

Satellite	Sensors
Landsat 1	RBV, MSS
Landsat 2	RBV, MSS
Landsat 3	RBV, MSS
Landsat 4	MSS, TM
Landsat 5	MSS, TM
Landsat 6	MSS, ETM
Landsat 7	ETM+

Sensors onboard:

- Return-Beam-Vidicon (RBV)
- Multispectral Scanner (MSS)
- Thematic Mapper (TM)
- Enhanced Thematic Mapper (ETM+)

	Landsat 1-3	Landsat 4-5	Landsat 7
altitude (km)	907-915	705	705
inclination	99.2	98.2	98.2
orbit	close to polar, sunsynchron	close to polar, sunsynchron	close to polar, sunsynchron
equator	9:30 localtime	9:30 localtime	10:00 localtime
revisit (d)	18	16	16
revolution (min)	103	99	99

Applications:

Landuse, Agriculture, Geology, Hydrology, Cartography, small-scale Mapping, Vegetation Analysis, Water Studies, Chlorophyll Absorption, Biomass Analysis, Vegetation Maps, Clouds and Snow Studies, Thermal Maps, Hydrothermal Maps

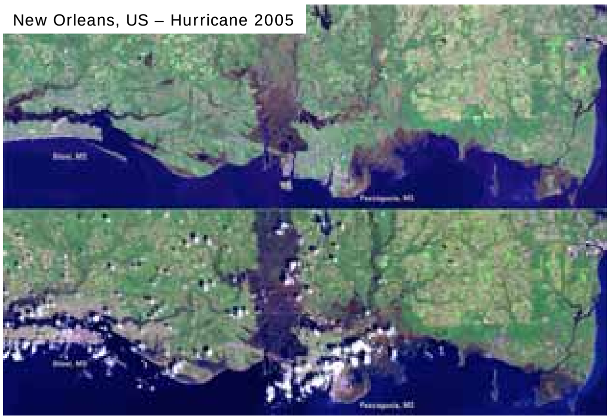
Spaceborne systems - LANDSAT

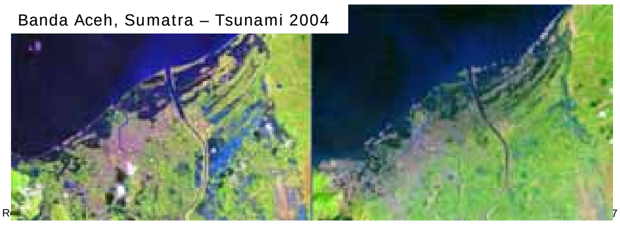
Landsat-7

CCRS Reception: July 1999 to present
Mission Date: April 15, 1999

- Earth observation/sun synchronous
- NASA - U.S.A.

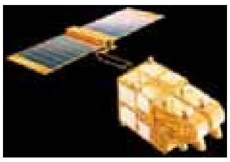
ETM - Enhanced Thematic Mapper	
Multispectral Bands	
Resolution	30 m
Bands (microns)	0.45-0.52 0.52-0.60 0.63-0.69 0.76-0.90 1.55-1.75 2.08-2.35
Multispectral Thermal Band	
Resolution	60 m
Band (microns)	10.4-12.5
Panchromatic Band	
Resolution	15 m
Swath	185 km
Band (microns)	0.5-0.9 (panchromatic)

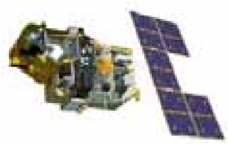

New Orleans, US – Hurricane 2005

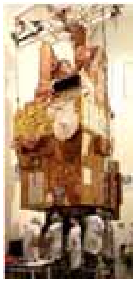

Banda Aceh, Sumatra – Tsunami 2004

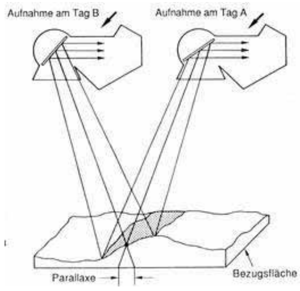
Spaceborne systems – SPOT series

http://www.spotimage.fr

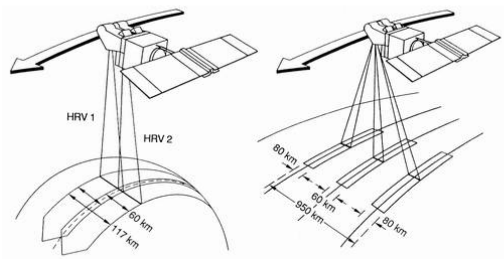

Spot 1, 2, 3


Spot 4


Spot 5



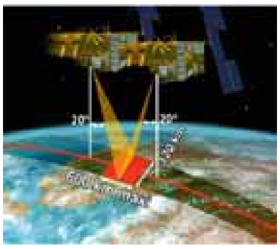
Satellite	SPOT 1,2,3	SPOT 4	SPOT 5
Mass	1800 kg	2760 kg	3000 kg
Satellite speed	7.4 km/s	7.4 km/s	7.4 km/s
Orbital cycle	26 days	26 days	26 days
Design lifetime	3 years	5 years	5 years
Orbit	*Circular Sun-synchronous*	*Circular Sun-synchronous*	*Circular Sun-synchronous*
Altitude	822 km	822 km	822 km
***Panchromatic* resolution mode** (black and white)	10 m	10 m	2.5 or 5 m
***Multispectral* resolution mode** (colour)	20 m	20 m	10 m



Spaceborne systems – SPOT 5

Mass	90 kg
Power	128W
Dimensions	1 x 1.3 x 0.4 m
Field of view	8°
Focal length	0.580 m
Detectors per line	12,000
Detector pitch	6.5 μm
Integration time per line	0.752 ms
Off-nadir angles: -forward -backward	 20.0° -20.0°
Spectral range (PAN)	0.49 μm - 0.69 μm
Ground sample distance: -across track -along track	 10 m 5 m
Modulation transfer	> 0.25 function
Signal-to-noise ratio	> 120

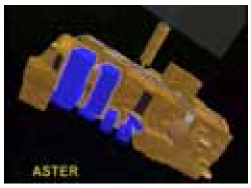
Production of worldwide DEM available at spotimage website

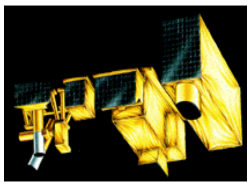


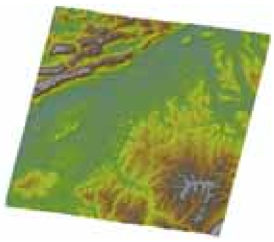
Spaceborne systems – ASTER

http://asterweb.jpl.nasa.gov/

Operational since	December 1999
Platform	EOS-AM1
Mass	90 kg
Power	128W
Instruments	VNIR – SWIR - TIR
Spectral range (IR)	0.52μm –11.3μm
Number of channels	14
Ground sample distance:	15m – 30m – 90m
Price	55$ per scene
VNIR:	
Focal length	0.329 m
Detectors per line	4100 (nadir) 5000 (backward)
Detector pitch	7 μm (nadir) 6 μm (backward)
Integration time per line	2.19 ms
Off-nadir angles: -backward	 -26.7°

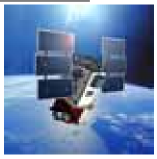




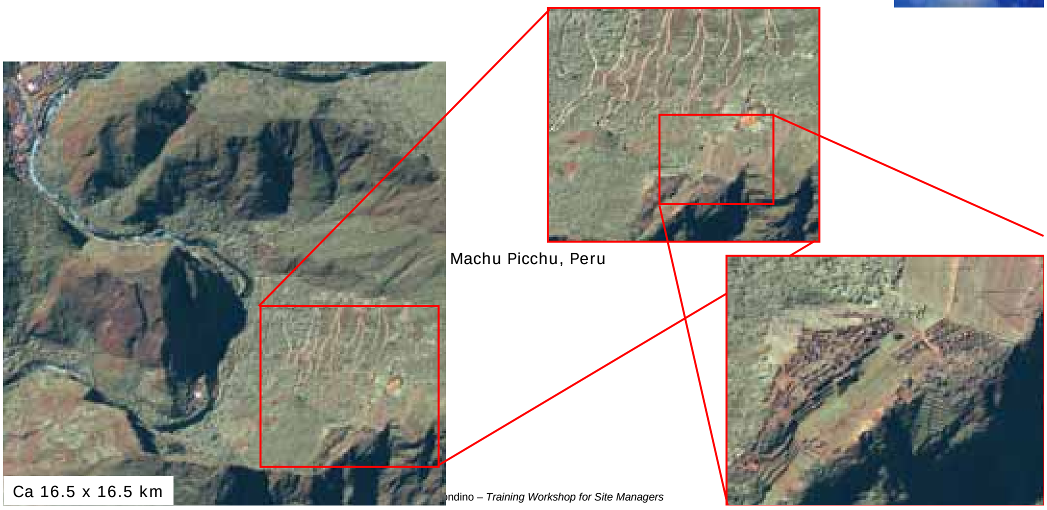


Spaceborne systems – QUICKBIRD

http://www.digitalglobe.com/



- Altitude: ca 450 km
- Revolution period: 93 min
- Revisit frequency: 1-3.5 days
- Sensors: 61 cm nadir Pan (up to 86 cm) + 2.4m multispectral



Machu Picchu, Peru

Spaceborne systems – QUICKBIRD

http://www.digitalglobe.com/

Bam, Iran: before and after the earthquake

Spaceborne systems – IKONOS

http://www.spaceimaging.com/

- Altitude: ca 680 km
- Revolution period: 98 min
- Revisit frequency: ca 3 days
- Sensors: 1m BW/RGB + 4m multispectral (R,G,B,NI)

Chichen Itza, Mexico

Spaceborne systems – IKONOS

http://www.spaceimaging.com/

Uxmal, Mexico

Spaceborne systems & UNESCO

UNESCO has recently started the OPEN INITIATIVE, a partnership with different space agencies to support and assist in the monitoring and documentation of World Heritage sites, natural hazards and for the sustainable development using satellite data

=> great interest (not only in the scientific community) towards mapping from satellite data

Different sensors available with resolution less than 5 m (QuickBird, IKONOS, SPOT-5/HRG, IRS-1C/1D, ...)

Summary:

- Almost instant availability in any world location
- Large field of view
- Increasing resolution (foot-print or GSD)
- Different products (PAN, multispectral, stereo, ...)
- High costs
- Documentation & Cartography (max 1 : 20 000 scale)
- Cannot (yet) replay standard aerial applications

Spaceborne systems - Costs

	IKONOS	Quickbird	EROS-A1	SPOT-5/ HRG	SPOT-5/ HRS	IRS-PAN 1C/-1D	ASTER - VNIR
Band	PAN RGB, NIR	PAN RGB, NIR	PAN	PAN	PAN	PAN	G,R,NIR
Ground Resolution (m)	1 4	0.61 2.44	2.6	2.5, 5	10(5)	5	15
Stereo-capability	Along / Across	Along / Across	Along / Across	Across	Along	Across	Along
Scene size (km x km)	11 x 11	16.5x16.5	12.5x12.5	60x60	120x60	70x70	60X60
Prize for stereo-scene	variable, min 4,500$	12,240$	variable, min 6200$	variable, min 9700$	only DEM (min 3000$)	5,000$	55$

Last update: May 2005

Spaceborne systems - Costs

SPOT color

Resolution	Full scene 60 x 60km	1/2 scene 40 x 40km	1/4 scene 30 x 30km	1/8 scene 20 x 20km
2.5m Spot 5*	13'000 CHF	-	-	-
5m Spot 5*	8'600 CHF	6'500 CHF	4'300 CHF	3'300 CHF
10m Spot 5	4'300 CHF	3'200 CHF	2'200 CHF	1'600 CHF
20m	3'000 CHF	-	-	-
20m before 2002	1'900 CHF	-	-	-

SPOT black/white

Resolution	Full scene 60 x 60km	1/2 scene 40 x 40km	1/4 scene 30 x 30km	1/8 scene 20 x 20km
2.5m	8'600 CHF	6'500 CHF	4'300 CHF	3'300 CHF
5m	4'300 CHF	3'200 CHF	2'200 CHF	1'600 CHF
10m	3'000 CHF	-	-	-
10m before 2001	1'900 CHF	-	-	-

NPOC image: 50% of prices above
* available in levels 1A and 2A
Price of a Spot stereopair = Price of two Spot images
SPOT-programming request: 1'300 CHF / priority programming request 5'000 CHF

orthorectification
per scene: CHF 500
per b/w and color pair of scenes + pansharpening: CHF 700
color conversion from false to true color: CHF 400.-

Prices for further SPOT-products (DTM, multitemporal scenes, SPOTViews) on request

Ikonos

Resolution and color	new imagery (newer than 6 months)	archived imagery (older than 6 months)
1m b/w or 4m color	*26 - 53 CHF/km^2	*20 - 40.5 CHF/km^2
1m color	*28 - 59 CHF/km^2	*21 - 47.5 CHF/km^2

* Prices of a Ikonos imagery depend on their location on earth, therefore always ask for a quotation

Minimum order area: 50 km^2 for archived imagery and 100 km^2 for new imagery

For detailed quotation please indicate:
- **area of interrest**: upper left and lower right corner in geographic, or swiss coordinates
- **type of image**: 1m b/w, 4 m color, 1m color or 1m b/w + 4m color (bundle)
- **date range of image**: new or archived

Quickbird

Type Resolution and color	new imagery to be programmed in standard tasking mode	archived imagery
standard / ortho - ready	minimum order 64km^2	minimum order 25km^2
0.6m b/w or 2.4m color 4 bands	26 CHF / km^2	20 CHF / km^2
0.6m color 3 or 4 bands	28 CHF / km^2	21 CHF / km^2
0.6m b/w and 2.4m color 4 bands (bundle)	31 CHF / km^2	25 CHF / km^2
basic imagery	scene of 16 x 16 km	scene of 16 x 16 km
0.6m b/w or 2.4m color 4 bands	7140 CHF	5440 CHF
0.6m b/w and 2.4m color 4 bands (bundle)	8500 CHF	6800 CHF

For detailed quotation please indicate:
- **area of interrest**: upper left and lower right corner in geographic, or swiss coordinates
- **type of image**: 0.6m b/w, 2.4 m color, 0.6m color or bundle
- **date range of image**: new or archived

Last update: Aug 2005, www.npoc.ch

Spaceborne systems – Data level and data provider

Available data:

Original data without radiometric correction
↓
Data with radiometric but not geometric correction
↓
Data with geometric correct (systematic errors) but not rectify
↓
Rectify data (e.g. projected on the ellipsoid)
↓
Orthophoto
↓
DTM
↓
Other products

costs

Spaceborne Data Provider:

EOS data gateway (NASA): NASA sensors
Spaceimaging: Ikonos, IRS-1C, IRS-1D (5m)
SpotImage: SPOT series
Eurimage: Quickbird, Ikonos, Landsat, Radarsat, ERS-1 e -2, JERS-1, NOAA
Innoter: TK-350, KVR-1000
...

Spaceborne systems – Available (free) products

• Great amount of images from different sensors / providers
• Great amount of already processed data (e.g. Digital Terrain Model)

Examples of available and **FREE / SPECIAL PRICE satellite images**:

http://medias.obs-mip.fr/oasis/

Possibility to get free/reduced price images if used for C.H. applications

http://www.spotimage.fr/html/_167_210_214_895_.php

Spaceborne systems – Available (free) products

Examples of available and **FREE / SPECIAL PRICE satellite images**:

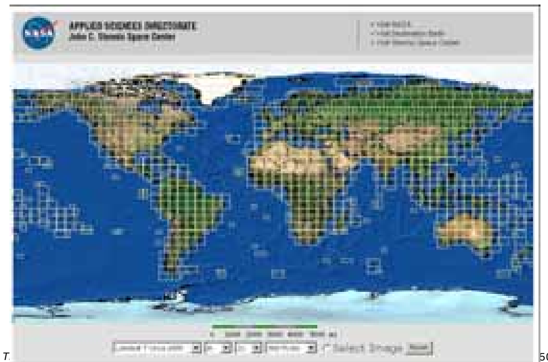
NASA datasets:

- Blue Marble (MODIS 1 km - 500 m resolution / monthly images)

http://bluemarble.nasa.gov

- Landsat collection (15-30 m resolution)

https://zulu.ssc.nasa.gov/mrsid/



Spaceborne systems – Available (free) products

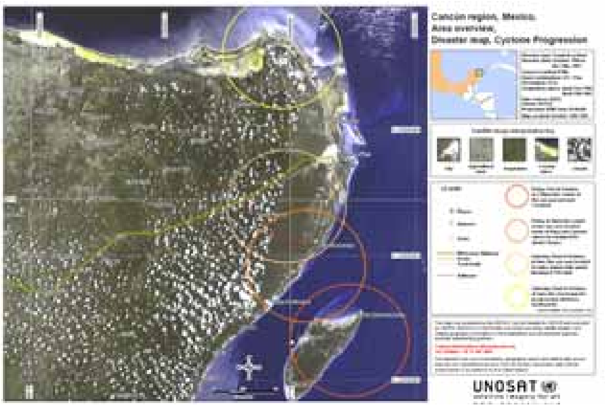
Examples of available and **FREE / SPECIAL PRICE satellite images**:

UNOSAT:

- images and maps available

http://unosat.web.cern.ch/unosat/asp/prod_free.asp?id=40

e-mail: info@unosat.org

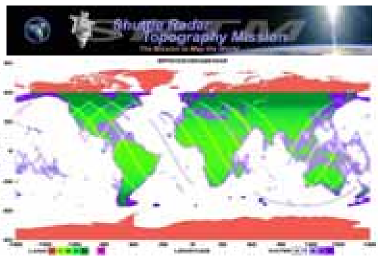


Spaceborne systems – Available (free) products

Examples of available and **FREE Digital Terrain Models**:

SRTM (Shuttle Radar Topography Mission)

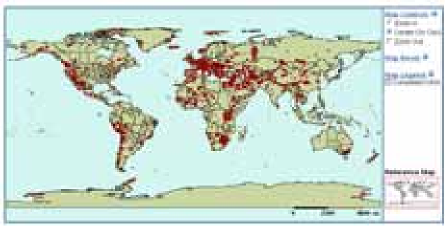
http://www2.jpl.nasa.gov/srtm/mission.htm



- Different resolution (15-30-90 m vertical accuracy)
- Coverage: 60 degrees N – 56 degrees S

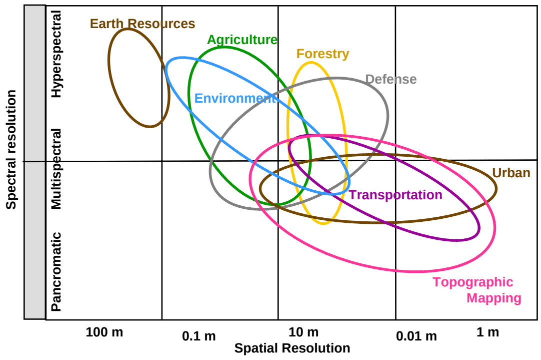
ASTER Digital Elevation Model

http://lpdaac.usgs.gov/aster/dem_map.asp



- Different resolution (7-50 m accuracy)
- Coverage: continuously updated / increased

Spaceborne systems – Data selection



- Experience
- Cloud cover
- Availability
- Kind of sensor (optic, radar)
- Geometric resolution
- Radiometric resolution (PAN for photogrammetry or MS for remote sensing)
- Temporal resolution (short for stereo, larger for multi-temporal applications)
- Price: it varies in function of quantity, area, location, level of the data, cloud cover, delivery time, archived data or to be acquired, …

Photogrammetry with …

500-700 km

+ spaceborne images

+ aerial images

altitude

+ helicopter / baloon images

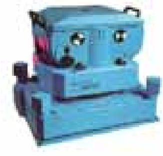
+ terrestrial images

1-10 m

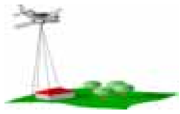
Airborne systems - Film images vs Dgital images

- Pro Film:
  - Still clearly higher resolution
  - Efficient and sure form for data archive
- Contra Film:
  - Expensive and time consuming digitization
  - Low (analog) data processing
  - Restriction in the multispectral channels

Leica RC30



Z/I Imaging_RMK-Top



- Pro Digital
  - elimination of film scanning and film development / storage
  - higher radiometric dynamics
  - better signal/noise ratio
  - Larger spectral bands
    - Film 300-900 nm
    - CCD 400-1100 nm

Starlabo STARIMAGER

Leica ADS40

Airborne systems - Film images vs Dgital images

Film camera vs Digital camera

www.vexcel.com

UltraCam - Vexcel

Airborne digital systems

- Airborne digital imaging systems: airborne surveying and remote sensing applications
  - cameras with frame sensor vs linear sensor
  + small-format systems (with < 15 MP size): terrain / vegetation classification
  + medium-format systems (e.g. 4000x4000 pixel)
  + large-format systems

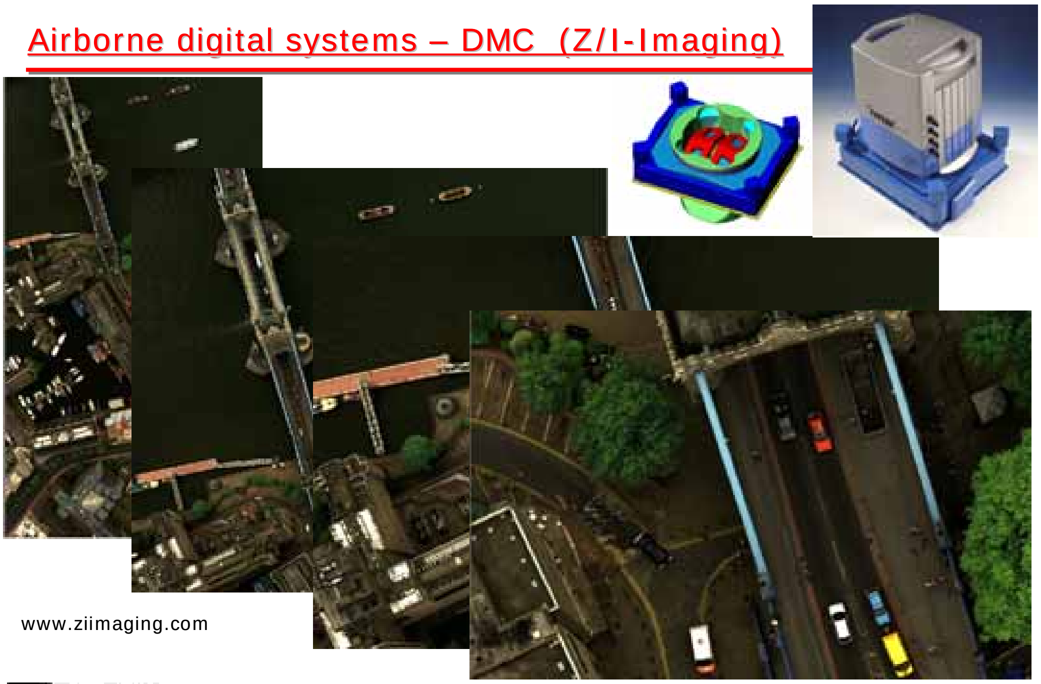
UltraCam-D

  + cost saving (elimination of film scanning and film development / storage)
  + time saving (direct digital acquisition to exploitation)
  + higher quality (higher radiometric dynamics and better signal/noise ratio)
  + multispectral image acquisition (panchromatic, color and color infrared)

Examples:

- DMC (digital modular camera) from Z/I-Imaging (14k × 8k)
- UltraCam-D from Vexcel Corporation (11.5k × 7.5k)
- ADS40 from Leica Geosystem (2 × 12k pixels)

Airborne digital systems – DMC (Z/I-Imaging)



www.ziimaging.com

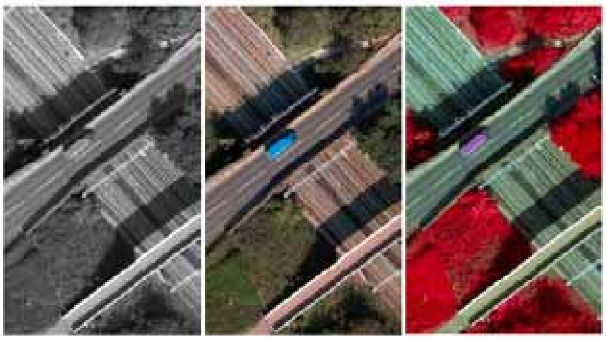
Airborne digital systems – UltraCAM (Vexcel)

Resolution of PAN images:

11,500 × 7,500 pixels (9 microns)

At the same time: PAN, Color, IR images

www.vexcel.com



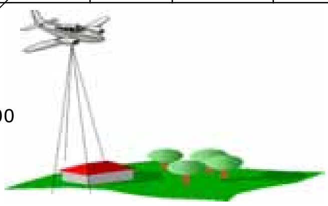
Panchromatic, colour and colour infrared images
(Copyright Simmons Aerofilms Ltd)

Airborne digital systems vs satellite (optical) data

- Better resolution (it depends from the scale / flight height) than satellite imagery
- Less availability (aerial case should be plan …)
- Less costs
- More commercial software to process aerial data
- For some applications (e.g. 3D city modeling) aerial images are still the best solution because of the scale / resolution (for maps or city modeling 1: 3000 - 10000)

Mission or Satellite	Ikonos-2	Quickbird-2	Orbview-3	SPOT 5	IRS-P5 (Cartosat-1)	FormoSat-2	EROS A1	Cosmos, many missions	Corona (KH-1 to KH-4), many missions	KH-7, many missions
Scale factor	68,100	51,100	170,000	762,500 HRG, 1,422,500 HRS	312,000	307,000	145,000	190,000-270,000	Variable, ca. 250,000 typical	Variable

Maps up to 1:20000



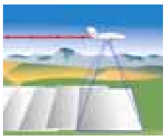
VS

Photogrammetry with ...

+ spaceborne images

500-700 km

+ aerial images



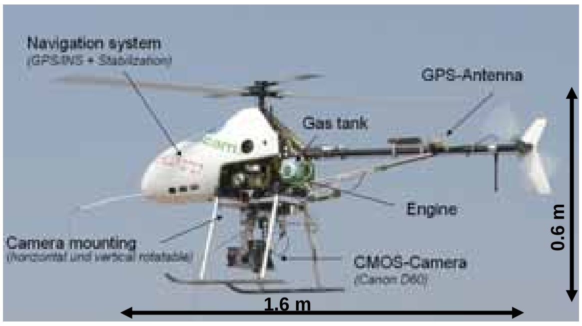
altitude

+ helicopter / baloon images

+ terrestrial images

1-10 m

Airborne digital systems – on an unmanned helicopter



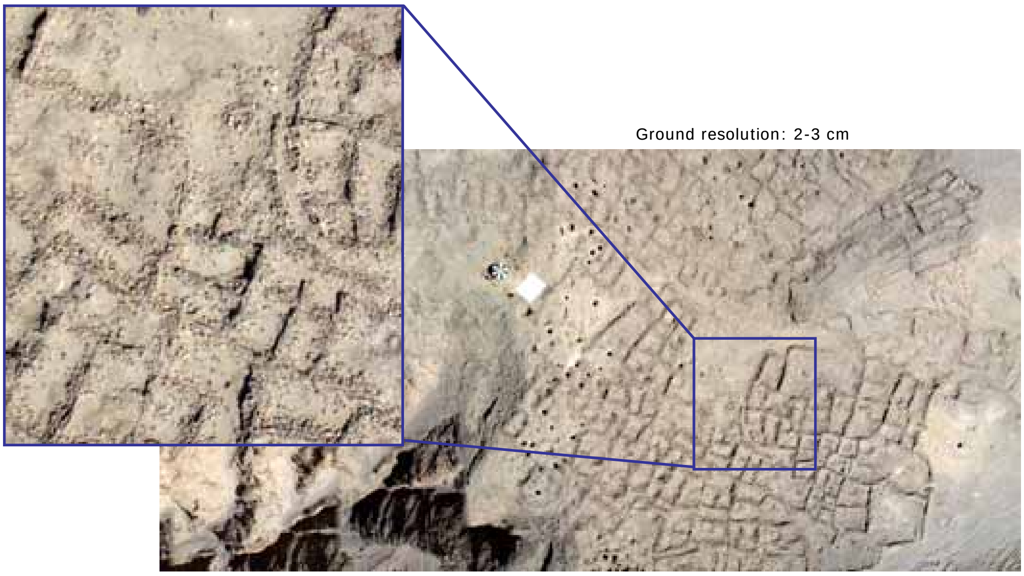
Canon D60/D10:

- Geometric resolution: 6.3 Mpixel (3072 x 2048), CMOS-Sensor
- Radiometric resolution: 48 Bit (16 Bit pro Kanal) im Raw-Format
- Focal length: 14.26 mm
- Sensor size: 22.7 x 15.1 mm (pixel size: 7.4 x 7.4 mm)

Rollei 6006:

- Image format: 6 cm x 6 cm
- Focal lenght: 40 mm/ 50 mm

Airborne digital systems – on an unmanned helicopter



Ground resolution: 2-3 cm

Pinchango Alto, Peru

Photogrammetry with ...

+ spaceborne images

+ aerial images

+ helicopter / baloon images

+ terrestrial images

Terrestrial systems

Digital and Analogue cameras:

(3D) measurements from images
- Time consuming
+ 3D and texture from the images
+ Results independent from the scene/object
+ Low costs
- Possible smooth effects on small details

Emerging alternative:

Laser Scanners:

Sensors which provide directly 3D info
- High costs
- Usually no texture
- Results depend on the type/quality of surface
+ Very fast acquisition
+ Able to acquire all the small details

• Triangulation or time delay principle
(short range) (long range)

Terrestrial Photogrammetry

Last trend: 3D modeling of (CH) objects

IMAGES

↓

PHOTOGRAMMETRIC PROCESSING

Photogrammetric workflow for the production of

Digital Surface Models (DSM),
orthoimages,
2D and 3D vector data with attributes,
photorealistic 3D models
traditional 2D maps
...

Processing of (digital) images – Photogrammetric pipeline

- Image acquisition → Satellite, airborne, terrestrial sensors
- Image preprocessing → Enhancement, filter
- Image orientation → Recover the sensor's parameters
- Matching and surface generation → Extract image correspondences and generate 3D data
- Texture Mapping → Create a photo-realistic 3D model
- Visualization, GIS products, ...

Scenes / Images Orientation - Sensor Modeling

- Find the relationship between image (2D) and ground (3D) coordinates

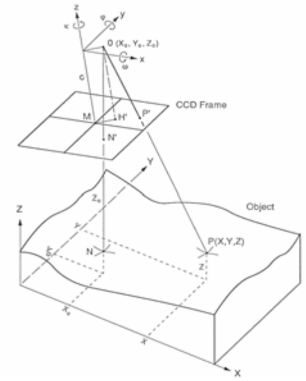
- Involved parameters:

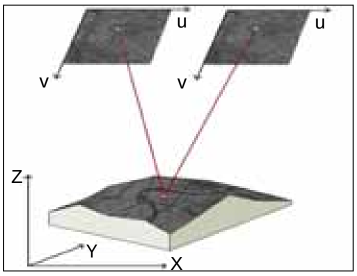
• Interior orientation parameters (camera constant, principal point position)

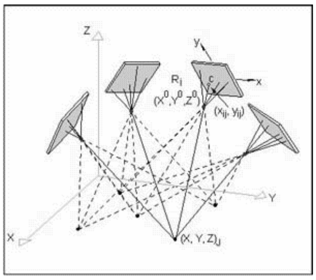
• Exterior orientation parameters (3 positions, 3 rotations)

• Additional parameters (to model systematic errors)

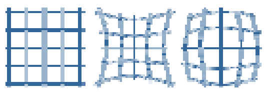
• 3D coordinates of object points







- radial distortion
- decentering distortion



Scenes / Images Orientation - Sensor Modeling

INPUT	ADJUSTMENT	OUTPUT
• image measurements • ground control points		• sensor parameters • 3D object coordinates

- Classical / Rigorous models (for satellite, airborne and terrestrial images):

• Describe the physical acquisition of the images

• Collinearity model

• Based on the determination of the sensor's internal and external orientation using ground information

- Empirical models (mainly for satellite images):

• Not based on physical models

• Relationship between image and ground coordinates described by polynomials or ratio of polynomials (max order 3)

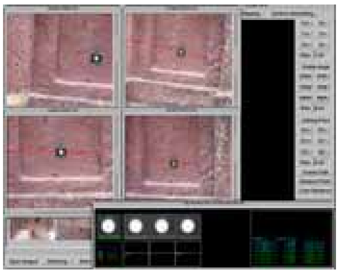
Matching and Surface Generation

Image Matching:

- Find 2D correspondences (image coordinates) between the images
- Automated / semi-automated / manual procedures
- 2D image coordinates transformed in 3D object coordinates using the sensor parameters

Manual measurements on analogue stereo images with an analytical plotter

Manual and semi-automated measurements on digital (stereo) images with an digital photogrammetric software

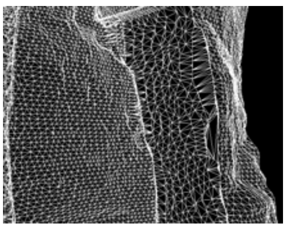


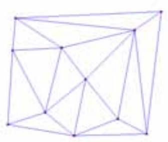
Semi- and fully automated measurements on digital (stereo) images with an digital photogrammetric software

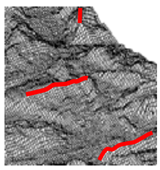
Matching and Surface Generation

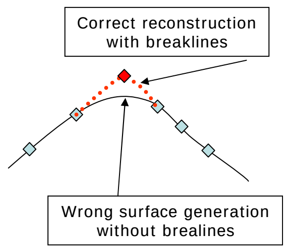
Surface Generation:

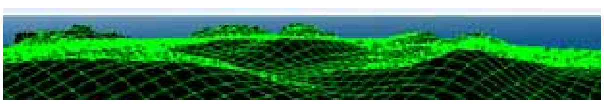
- given the recovered 3D point ("point cloud") => generate a surface model describing the measured object => 3D model generation
- 'Mesh generation' or 'surface triangulation'
- Breaklines (edges, streets, ridges, etc.) for the correct surface reconstruction ('modeling')







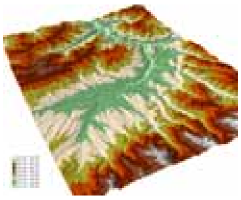
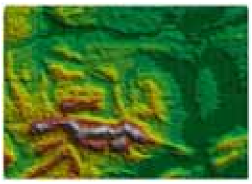
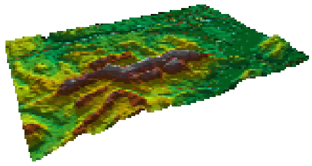


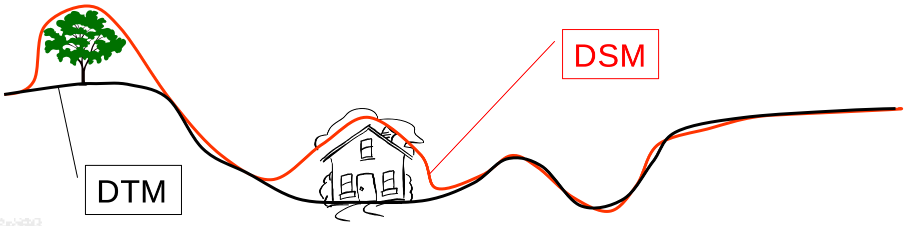


Matching and Surface Generation

Surface Generation:

- In case of landscape: Digital Terrain Model (DTM), Digital Surface Model (DSM)



Texture Mapping

- Use image information to add photo-realism to a 3D model

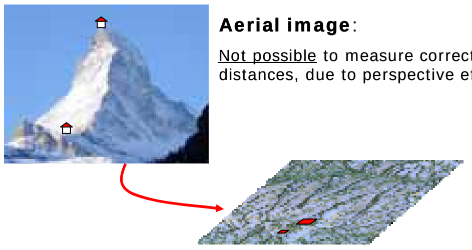
- Satellite / Airborne case:

Orthophoto generation and direct projection onto the 3D geometry of the model

- Terrestrial case:

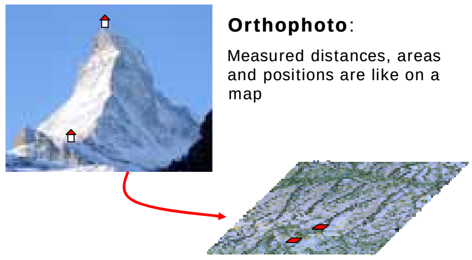
Image information projected onto the 3D geometry using the sensor parameters


Texture Mapping - Orthophoto



Aerial image:

Not possible to measure correct distances, due to perspective effects



Orthophoto:

Measured distances, areas and positions are like on a map

Aerial image:

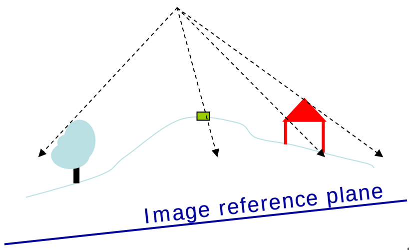
Overlapping of image and vector data is not consistent / correct

Orthophoto:

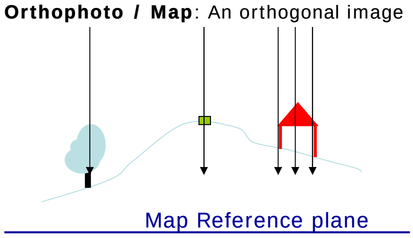
Correct overlap between image and vector data

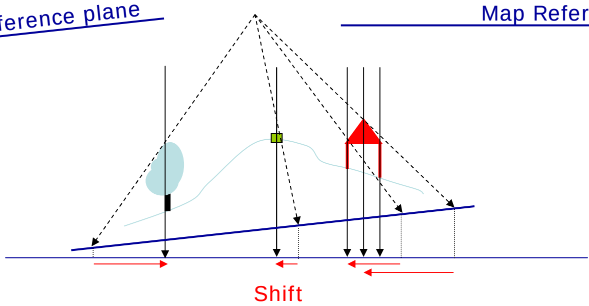
Texture Mapping - Orthophoto

Image: A central perspective projection, generally tilted



Orthophoto / Map: An orthogonal image



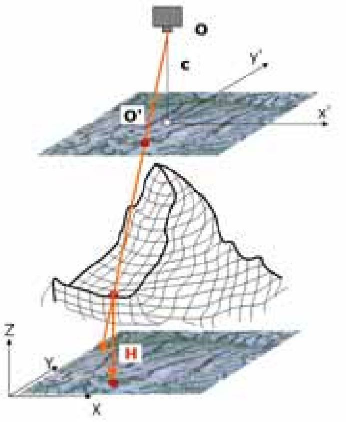


Orthophoto

- geometrically corrected (aerial / satellite) image
- variations in scale and displacements (due to tilted acquisition and terrain relief) are removed ('image rectification')

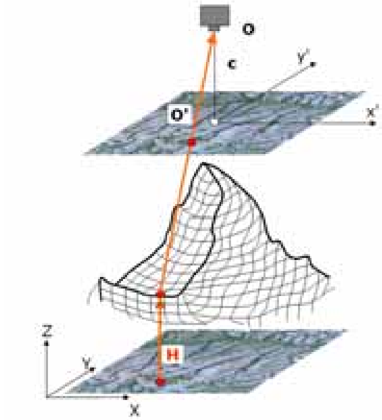
Texture Mapping – Orthophoto generation

Direct Method



- Pixel position in original image ⇒ H'(x,y)
- Collinearity equation ⇒ H(X,Y)
- DTM Interpolation ⇒ H(X,Y,Z)
- Pixel coordinate in the orthophoto H(X,Y)

Indirect Method



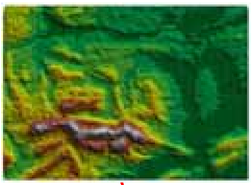
- Pixel position in orthophoto ⇒ H(X,Y)
- DTM Interpolation ⇒ H(X,Y,Z)
- Collinearity equation ⇒ H'(x',y')
- Interpolation of grey-value in the original image

Texture Mapping - Orthophoto

- Errors in the orthophoto:

The use of a DTM that does not include building, bridges, etc. leads to wrong results (correctness only on the ground)

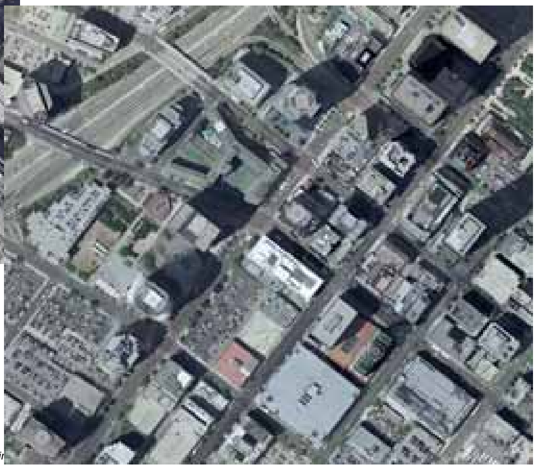
- **True orthophoto** => use of DTM + 3D models of building (i.e. DSM)



Texture Mapping – True Orthophoto

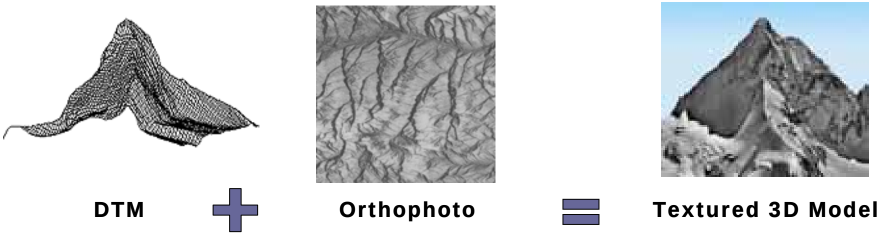
orthophoto

True-orthophoto



Texture Mapping with orthophoto

- The orthophoto is 'georeferenced' (each point in the image has a geographic coordinate)
- The orthophoto can be simply overlapped onto the DTM/DSM

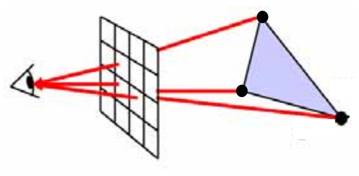


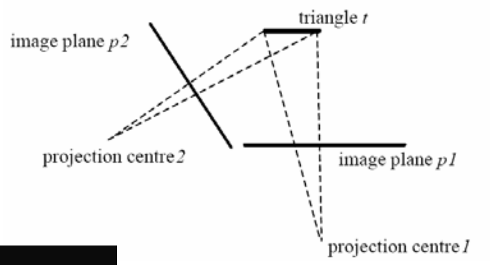
- An orthophoto can also be generated for terrestrial images

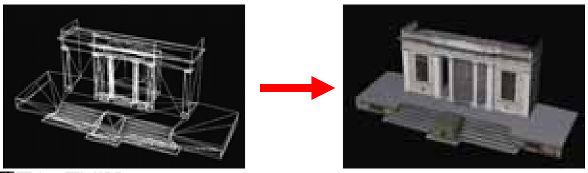
Texture Mapping of complex 3D model

- In case of complex 3D models, the orthophoto is not really useful

- The texture mapping is generally performed 'back-projecting' the triangles of the 3D polygonal model using the sensor parameters and assigning to each triangle the colors read in the image (in case of multiple images, an average is done)





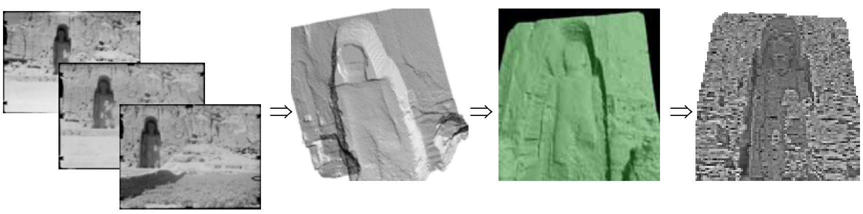


Visualization

measurements ⇒ surface reconstruction ⇒ 3D modeling ⇒ visualization

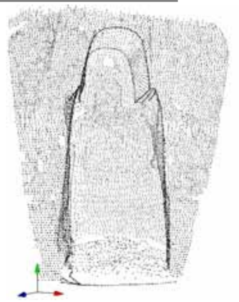
3D model visualization ⇒ unique product of interest for "external world"

realistic/accurate visualizations are required

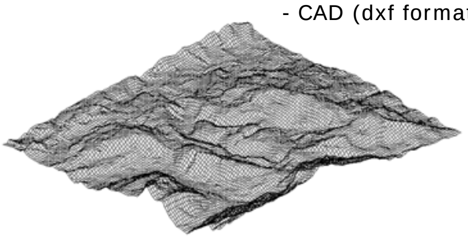


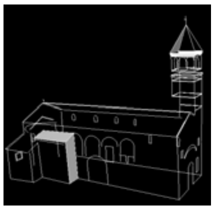
Visualization

3D Point mode: - easiest way, only points
- not useful for DTM (millions of points)
- more used in close-range photogrammetry
- point clouds with color



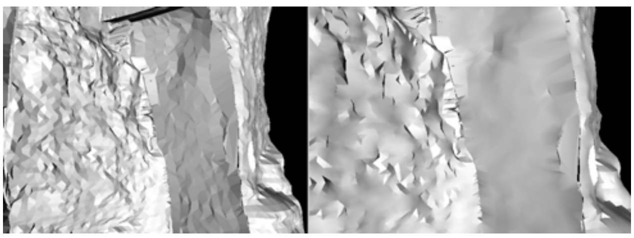
Wireframe mode: - easy way (points, lines, edges)
- trasparent drawing (no hidden surface removal)
- CAD (dxf format)



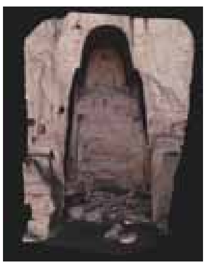


Visualization

Shaded mode: - assigniment of surface properties to the object (colour, normal information, reflectance, trasparency



Textured mode: - photorealistic visualization
- single/multi texture
- images/orthophotos/maps
- computer memory required



Animation

3D city model

NASA Blue Marble data

NY from the space