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Ordnance Survey

Tutorial 10

Information extraction from high resolution optical satellite sensors

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Contents

1. Introduction (definition of HR, current HR sensors, main characteristics, technological alternatives) EB
2. Image quality, radiometric analysis, preprocessing EB
3. Geometric sensor models, sensor orientation KJ
4. Automated DSM generation KJ
5. Orthoimage generation EB
6. Object extraction (mainly roads and buildings) EB
7. Land use and land cover mapping DH
8. Topographic mapping, change detection and map update DH
9. Conclusions and outlook KJ

Section 1

Introduction (definition of HR, current HR sensors, main characteristics, technological alternatives)

Emmanuel Baltsavias

Role of satellite imagery

- Imagery an increasingly important source for geodata acquisition and update
- Satellite images generally cheaper than aerial images
- Repetitive coverage, increasing temporal resolution
- Increasing spatial, radiometric and spectral resolution
- Many satellites, increasing number in future

High spatial resolution (HR) satellites

- Ground Sampling Distance (GSD) down to 0.61 m, 0.4 m in 2007, 0.25 in 2008?
- Almost all are stereo capable
- High geometric accuracy potential
- Increasing support by commercial software packages
- Increasing number (5 new systems from mid 2005 to mid 2006)

But,

- Some too new, very little known about them
- Not high availability. Hopes for improved availability with more such systems planned
- High costs for many sensors. Hopes for lower costs with increasing competition and non-commercial systems (like Japanese ALOS-PRISM, Indian CARTOSAT-1) and small, low-cost HR satellites (like Topsat, UK)

How is a HR sensor defined here?

- Definition changes with time. 10 years ago, 10 m GSD was considered HR, not now
- Here HR, if panchromatic (PAN) GSD max. about 3 m
- Multispectral channels (MS) usually employed and have 2-4 times larger GSD
- Here only optical sensors, not microwave or laser scanners
- Pure military systems not treated here
- Most optical HR sensors use linear CCDs
- Many have military heritage, and are still used for dual purposes
- Some data for HR sensors kept secret. Useful source of info http://directory.eoportal.org/

Specifications of current HR satellite missions (status January 2008, in chronological order)

Mission or Satellite	Ikonos-2	EROS A1	Quickbird-2	SPOT 5	Orbview-3	FormoSat-2 (formerly ROCSat-2)	IRS-P5 (Cartosat-1)	Corona (KH-1 to KH-4), many missions	KH-7, many missions	Cosmos [1], many missions
Sensor	OSA	PIC	BHRC60	HRG, HRS	OHRIS	RSI	2 PAN cameras	Stereo panoramic cameras	High Resolution Surveillance Camera	KVR 1000 panoramic camera (2 working alternatively)
Country	USA	Israel	USA	France, Belgium, Sweden	USA	Taiwan	India	USA	USA	Russia
System type	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Military, declassified	Military, declassified	Commercial
Launch date or duration	9/1999	12/2000	10/2001	5/2002	6/2003	5/2004	5/2005	1960-1972	1963-1967	1981-2000
Sensor type	digital	digital	digital	digital	digital	digital	digital	film	film	film
PAN GSD (m) (across x along track)	1 (actually 0.82)	1.9 1 or 1.4 (oversampled)	0.61	5 or 2.5-3 (oversampled) HRG 10 x 5 HRS	1	2	2.5	2-140	At nadir down to 0.45-0.5	2
PAN Pixels of line CCD / Pixel spacing (μm)	13,816 / 12	7,043 (2 lines) / ca. 13	27,568 / 12	12,000 (2 lines for HRG) / 6.5	8,000 / 6 x 5.4, numbers shown here for 2 staggered lines	12,000 / 6.5	12,288 (x 2 staggered lines) / 7	NA	NA	NA
Flying height (km), Focal length (m)	681, 10	ca. 500, 3.4	450, 8.832	818-833, 1.082 HRG 0.58 HRS	470, 2.77	888, 2.896	618, 1.945	Variable, 0.6069	Variable, 0.96	Variable (190-270), 1

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No. of MS Channels / GSD (m)	4 / 4	0	4 / 2.44	(excl. Vegetation instrument) 4 / 10 and 20	4 / 4	4 / 8	0	0	very few color & CIR images	0
Stereo [2]	along-track, across-track	along-track, across-track	along-track, across-track	along-track, across-track	along-track, across-track	along-track, across-track	along-track	along-track	few images in stereo	no stereo
Swath width (km) or Image film dimensions (cm)	11	14, 10 for oversampled images	16.5	60 HRG, 120 HRS	8	24	27	5.54 x 75.69 (across)	22.8 x variable (across)	18 x 72 (across)
Field Of Regard [3] (deg)	45, up to 60 deg images shot	45	45	27 (HRG, only across track)	50	45	23 (across)	NA	NA	NA
TDI	Y	N, Asynchronous scanning	Y	N	N, asynchronous scanning equivalent to 10 TDI lines, and 4 variable integration times	N	N	NA	NA	NA
Along track triplette ability	Y	Y	?	N	?	?	N	N	N	NA
Body rotation angular rate [4] (deg/sec)	up to > 1	1.8	0.5-1.1	NA	?	0.4-0.75	?	NA	NA	NA

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Mission or Satellite	Ikonos-2	EROS A1	Quickbird-2	SPOT 5	Orbview-3	FormoSat-2	IRS-P5 (Cartosat-1)	Corona (KH-1 to KH-4), many missions	KH-7, many missions	Cosmos, many missions
FOV (deg) or film area coverage	0.93	1.5	2.12	4.13 HRG 7.7 HRS	0.97	1.54	2.49	14 x 189 km (typical)		40 x 160 km (typical)
Quantization bits	11	11	11	8	11	12	10	NA	NA	NA
Scale factor	68,100	145,000	51,100	762,500 HRG, 1,422,500 HRS	170,000	307,000	312,000	Variable, ca. 250,000 typical	Variable	190,000-270,000
Stereo overlap (%)	up to 100	up to 100	up to 100	up to 100	up to 100	up to 100	up to 100	up to 100	?	6-12
B/H ratio	variable	variable	variable	up to 1.1 HRG, 0.8 (40 deg.) HRS	variable	variable	0.62 (31 deg.)	0.60 (30 deg.)	?	NA

[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 if otherwise stated in the table. 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.

Specifications of current HR satellite missions (status January 2008, in chronological order)

Mission or Satellite	TOPSAT	ALOS	EROS B	RESURS DK-1	KOMPSAT-2	Cartosat-2	Worldview-1	GEOEYE-1
Sensor	RALCam1	PRISM / AVNIR-2	PIC-2	ESI		2 PAN cameras	WorldView-60	
Country	UK	Japan	Israel	Russia	Korea	India	USA	USA
System type	Commercial / Experimental	Commercial / Experimental	Commercial	Commercial	Commercial	Commercial	Commercial / Military	Commercial / Military
Launch date or duration	10/2005	1/2006	4/2006	6/2006	7/2006	1/2007	9/2007	Planned in 2008
Sensor type	digital	digital	digital	digital	digital	digital	digital	digital
PAN GSD (m) (across x along track)	2.8	2.5 (AVNIR-2 10)	0.7	1 @ 350 km height (actually about 0.8)	1	1 (actually about 0.8)	0.5 (0.45 for US Government)	0.5 (0.41 for US Government)
PAN Pixels of line CCD / Pixel spacing (μm)	6,000 / 7 (2000 / 14 for MS)	PRISM 5,000 (x 6-8) , selected 28,000 N, or 14,000 N/F/A[1] / 7 (AVNIR-2 7,000 / ca. 11.6)	10,000 (2 CCD lines) / ca. 7	36,000 (using 1,024 pixel line CCDs) / 9	15,000	12,288 / 7	39,100 / 8	> 37,000 / 8
Flying height (km), Focal length (m)	686, 1.68	691.65, 1.939 (AVNIR-2 0.8)	500, 5	350-610, 4	685	635, 5.6	496, 8.8	684, 13.3

[1] N, F, A = Nadir, Fore, Aft telescopes

Specifications of current HR satellite missions (status January 2008, in chronological order)

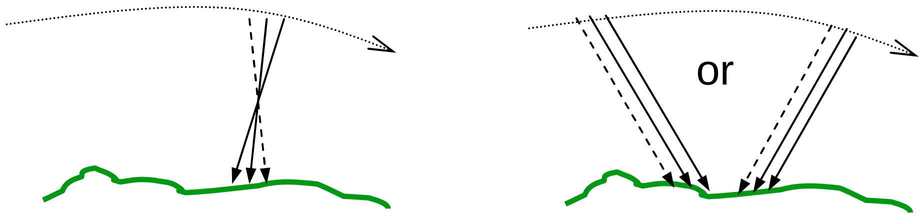
Mission or Satellite	TOPSAT	ALOS	EROS B	RESURS DK-1	KOMPSAT-2	Cartosat-2	Worldview-1	GEOEYE-1
No. of MS Channels / GSD (m)	3 / 5.6	4 / 10	0	3 / 2.5-3.5	4 / 4	0	0	4 / 1.64
Stereo [2]	along-track, across-track	along-track (AVNIR-2 across-track)	along-track, across-track	across-track	Y	along-track, across-track	along-track, across-track	along-track, across-track
Swath width (km) or Image film dimensions (cm)	15 PAN, 10 MS	70 N, 35 N/F/A (AVNIR-2 70)	14	28.3 @ 350 km height	15	9.6	17.6	15.2
Field Of Regard [3] (deg)	30	1.5 (AVNIR-2 44)	45	30, cross track	56, cross track 30 along track	45	40/45 (along/across)	60
TDI	N, asynchronous scanning equivalent to 8 TDI lines	N	Y (96 lines), synchronous and asynchronous	Y (128 lines, for PAN and MS)	Y (32 lines), 2200 to 7100 line rate depending on TDI stages and roll/Pitch tilt	N, asynchronous scanning	Y (64 lines)	Y
Along track triplette ability	?	Y (AVNIR-2 N)	Y	N	?	?	Y	Y
Body rotation angular rate [4] (deg/sec)	?	NA	?	?	?	?	4.5	2.4

Specifications of current HR satellite missions (status January 2008, in chronological order)

Mission or Satellite	TOPSAT	ALOS	EROS B	RESURS DK-1	KOMPSAT-2	Cartosat-2	Worldview-1	GEOEYE-1
FOV (deg) or film area coverage	2.4 (larger than effective FOV of 1.2-1.4)	5.8 N, 2.63 N/F/A (AVNIR-2 5.8)	1.5	4.6?		0.92	2.04	1.28
No. of quantization bits	8?	8	10	10	10	10	11	11
Scale factor	408,000	357,000 (AVNIR-2 865,000)	100,000	87,500 @ 350 km height		113,400	56,400	51,400
Stereo overlap (%)	up to 100	up to 100	up to 100	up to 100	up to 100	up to 100	up to 100	up to 100
B/H ratio	variable	fixed, 1 for F/A (AVNIR-2 Variable)	variable	variable	variable	variable	variable	variable

Important characteristics of HRS

- Very narrow across-track Field of View
  - down to 0.9 deg for Ikonos
  - small influence of height errors, accurate orthoimages when high sensor elevation, even with poor quality DTM/DSM
- Variable scanning modes – reverse, forward (Ikonos, Quickbird)



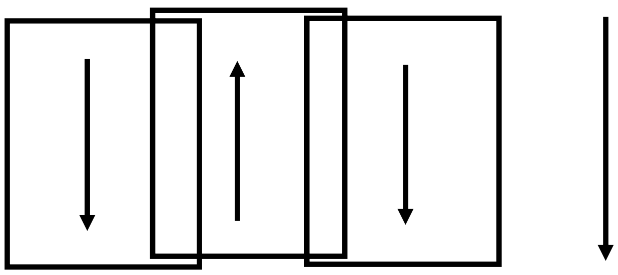
Flight direction from N to S

First line scanned is dotted

Usual and preferred mode is reverse

Forward (scan from S to N)   Reverse (scan from N to S)

Forward used to scan more images within a given time, by reducing time needed to rotate the satellite body, e.g. when acquiring multiple neighbouring strips, or triplettes within a strip. The satellite body rotates continuously with an almost constant angular velocity

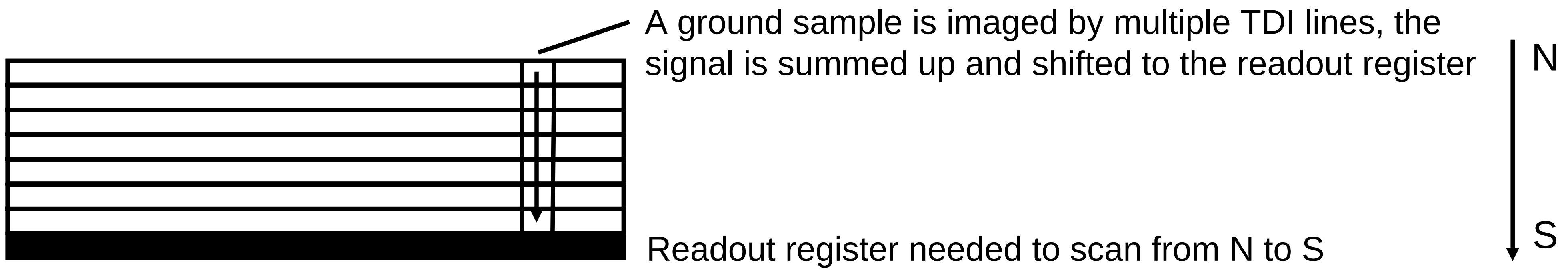


Flight direction from N to S

Middle strip scanned in forward mode

Important characteristics of HRS

- Often use of TDI (Time Delay and Integration) technology (Ikonos, Quickbird)
  - Aim: to increase pixel integration time in scanning direction for better image quality and signal to noise ratio, by summing up the signal of multiple lines
  - Used especially for fast moving objects (or platforms) and low light level conditions
  - Necessary, especially when the GSD is small (thus, used mainly for PAN only)
  - TDI is rectangular CCD chip with many lines (called also stages). Ikonos and Quickbird use max. 32 stages. How many are actually used is programmable from the ground station. Usually 13 with Ikonos. Use of more can lead to saturation. They can have 1 or 2 readout registers. The readout register must be at the TDI end in the scanning direction. Ikonos and Quickbird use older technology with 1 register. Thus, need 2 TDI to scan in both forward and reverse mode.



Important characteristics of HRS

- Rotation of satellite from S to N done also for other reasons

a) to achieve a smaller GSD (the nominal one) in flight direction

With Quickbird, GSD in flight direction would be larger than 0.61 m in PAN, for the given satellite speed and pixel integration time. Thus, the satellite rotates from S to N a bit to achieve 0.621 m GSD. This happens in both Reverse and Forward mode !

Satellite body rotation can introduce nonlinearities in the imaging geometry.

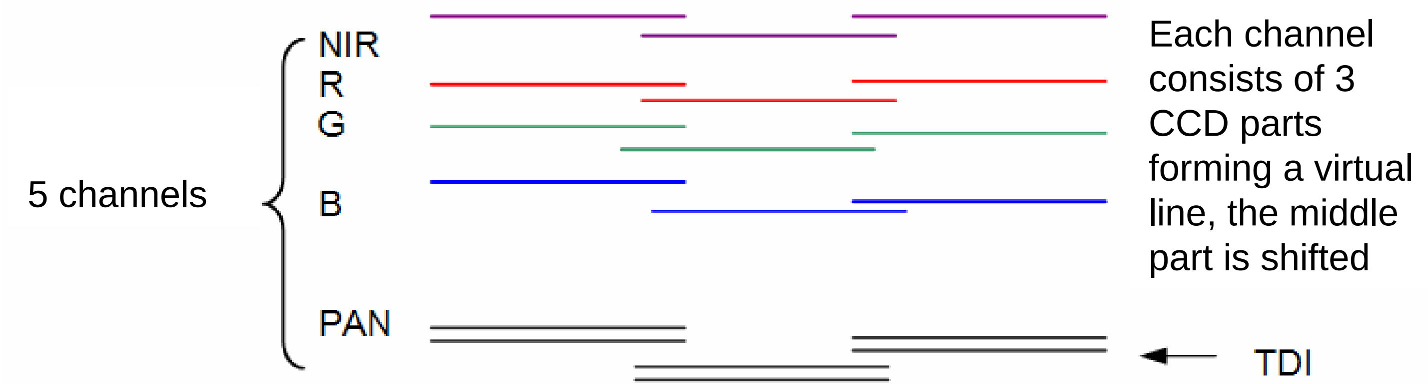
b) to increase pixel integration time and achieve better image quality, when the sensor does not use TDI, e.g. EROS A1, TopSat

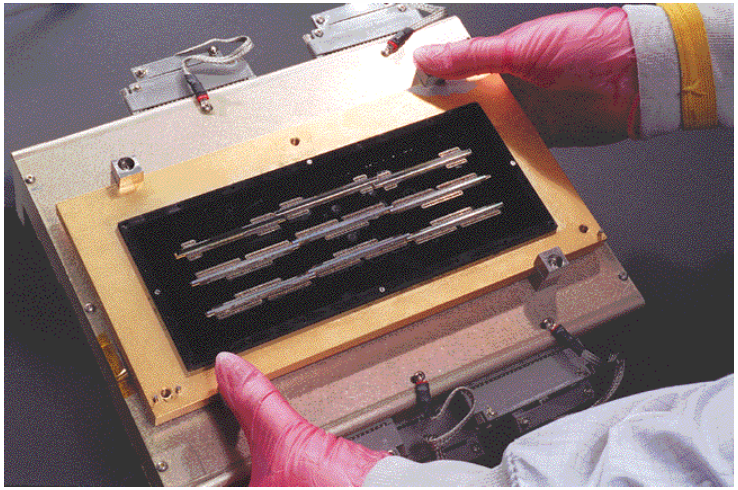
This feature is inferior to TDI, can introduce nonlinearities in the imaging geometry and may cause pixel and edge smearing (unsharpness)

In both cases, the imaged earth part (given often as line scan frequency for line CCDs), is shorter than the ground track of the satellite. A linescan frequency of e.g. 1500 lines/s, means 1/1500 s (0.67 ms) integration time (IT). This is also called asynchronous scanning mode, espec. in case b)
Note: linear CCDs can have an exposure time (effective IT) smaller than the nominal IT. We assume that satellite firms use the term IT in the sense of exposure time.

Important characteristics of HRS

- Use of multiple CCDs
  - butted (Ikonos, Quickbird) to increase the across track FOV (swath width)
  - staggered (SPOT-5 HRG, Orbview-3) to decrease, usually by about the half, the GSD
- Multiple butted CCDs (example below Ikonos)





From top to bottom:

- MS linear CCD (4 channels/lines)

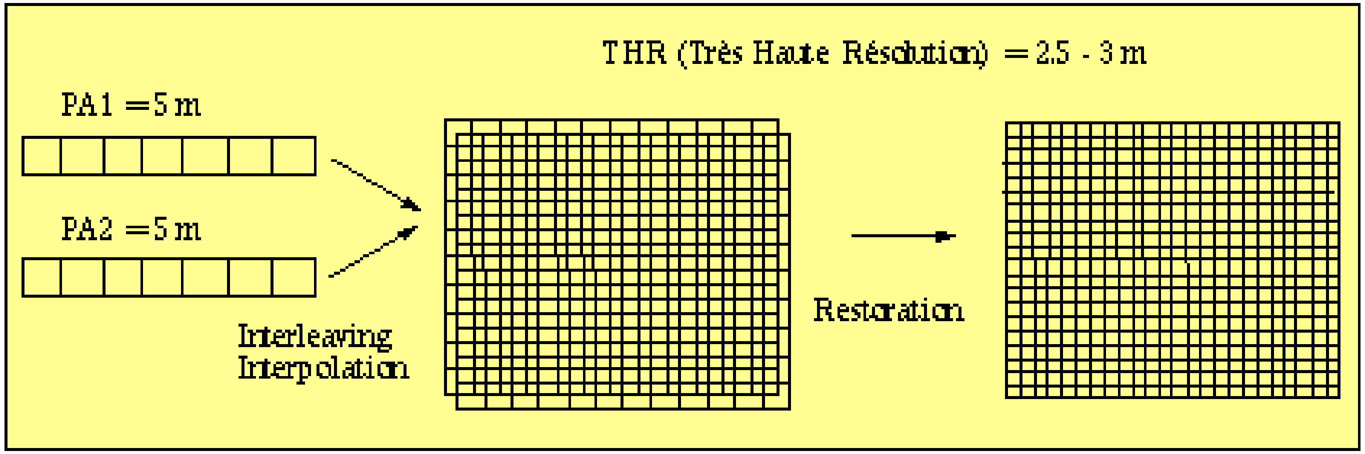
- Reverse TDI PAN (32 lines/stages)

- Forward TDI PAN (32 lines/stages)

Quickbird has similar focal plane but double width and 6 CCD parts per virtual line, with a total of 18 linear CCD chips and 408 partial CCD lines!

Important characteristics of HRS

- Staggered CCDs (example here SPOT-5 HRG)
  - Used to decrease the GSD by avoiding too long focal length, small pixel spacing or low flying height
  - Used primarily only for PAN
  - Use of 2 identical CCD lines, shifted in line CCD direction, by 0.5 pixel
  - Distance of 2 lines in scanning direction, as small as possible, for SPOT 3.45 pixels
  - The data from 2 CCDs are interleaved and interpolated with various algorithms
  - Then, often a restoration (denoising) is performed
  - Thus, for SPOT-5 HRG the original GSD of 5 m, can be improved to 2.5 – 3.5 m



Important characteristics of HRS

- Multispectral CCDs
  - Often the pixel size given by the firms, e.g. 48 microns for Ikonos and Quickbird, is not correct.
  - Linear CCDs with so large pixel size not available in standard products
  - Usually the MS CCDs are identical to the PAN CCDs with very thin filters covering the pixels, thus for Ikonos and Quickbird they have 12 microns pixel size.
  - The larger effective pixel size (e.g. 48 microns) is achieved in scanning direction by increasing the integration time (e.g. for Ikonos by 4) and in the CCD line direction by averaging (binning) of pixels (e.g. 4 pixels)
  - This mode of generation leads to better image quality than producing images with real 48 microns pixel size. This may explain why geometric accuracy with MS images is only about 2 times worse than that of PAN, and not 4 times as might have been expected.

Important characteristics of HRS – Stereo Acquisition

- Along-track
  - Through satellite body pointing
  - Through multiple PAN CCDs (at least 2, usually 3)

- Across-track
  - Through satellite body pointing
  - Through deflection of image rays (e.g. by mirror)

Along-track and across-track mean here, quasi-simultaneous acquisition and acquisition from different orbits with time delay, respectively.

NOTE: across-track stereo possible also quasi-simultaneously with sat body pointing, so above time-related terminology is better.