TUTORIAL

Extraction of Geospatial Information from High Spatial Resolution Optical Satellite Sensors

E. Baltsavias[1],L. Zhang [2], D. Holland [3], P.K. Srivastava [4], B. Gopala Krishna [4], T.P. Srinivasan [4]

[1] Institute of Geodesy and Photogrammetry, ETH Zurich, Wolfgang Pauli Str. 15, CH-8093 Zurich, Switzerland, manos@geod.baug.ethz.ch

[2] Institute for Photogrammetry and Remote Sensing, Chinese Academy of Surveying and Mapping, 16 Beitaiping Road, Haidian District, Beijing 100039, P.R.China, zhangl@casm.ac.cn

[3] Ordnance Survey, Romsey Road, Southampton SO16 4GU, UK, David.Holland@ordnancesurvey.co.uk

[4] Space Applications Centre, ISRO, Ahmedabad 380 015, India, pradeep@ipdpg.gov.in

Contents

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 June 2006)

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 (mm)	13,816 / 12	27,568 / 12	8,000 / 6 x 5.4, numbers shown here for 2 staggered lines	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

Specifications of current HR satellite missions (status June 2006)

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, asynchronous scanning equivalent to 10 TDI lines, and 4 variable integration times	N	N	N	N, asynchronous scanning	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

Specifications of current HR satellite missions (status June 2006)

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)	
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 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 June 2006)

Mission or Satellite	RESURS DK-1	TOPSAT	ALOS	EROS B
Sensor	ESI	RALCam1	PRISM / AVNIR-2	PIC-2
Country	Russia	UK	Japan	Israel
System type	Commercial	Commercial / Experimental	Commercial / Experimental	Commercial
Launch date or duration	6/2006	10/2005	1/2006	4/2006
Sensor type	digital	digital	digital	digital
PAN GSD (m) (across x along track)	1 @ 350 km height	2.86	2.5 (AVNIR-2 10)	0.7
PAN Pixels of line CCD / Pixel spacing (mm)	28,000? / 11.4?	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 / ca. 7
Flying height (km), Focal length (m)	350-600, 4	686, 1.68	691.65, 1.939 (AVNIR-2 0.8)	ca. 500, 5

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

Specifications of current HR satellite missions (status June 2006)

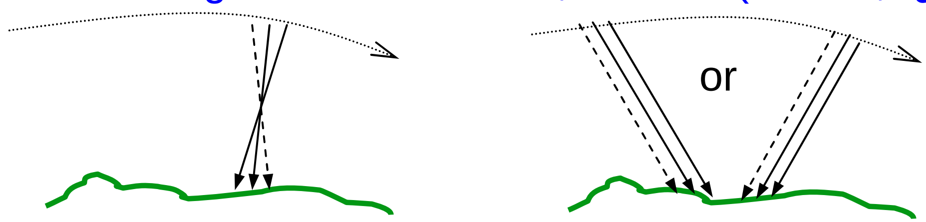
Mission or Satellite	RESURS DK-1	TOPSAT	ALOS	EROS B
No. of MS Channels / GSD (m)	3 / 2-3	3 / 5.7	4 / 10	0
Stereo [2]	across-track	along-track, across-track	along-track (AVNIR-2 across-track)	along-track, across-track
Swath width (km) or Image film dimensions (cm)	28 @ 350 km height	17.14 PAN, 11.44 MS	70 N, 35 N/F/A (AVNIR-2 70)	7
Field Of Regard [3] (deg)	30, cross track	30 in roll and pitch	1.5 (AVNIR-2 44)	45+
TDI	?	N, asynchronous scanning equivalent to 8 TDI lines	N	Y (96 lines)
Along track triplette ability	N	?	Y (AVNIR-2 N)	Y
Body rotation angular rate [4] (deg/sec)	?	?	NA	?

Specifications of current HR satellite missions (status June 2006)

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



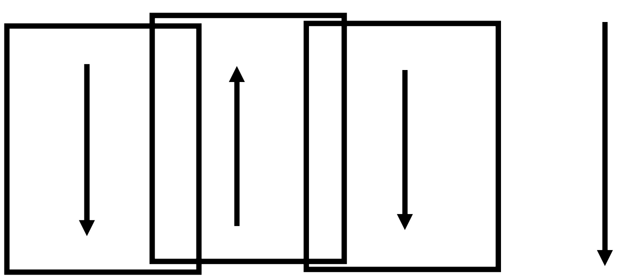
Flight direction from N to S

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

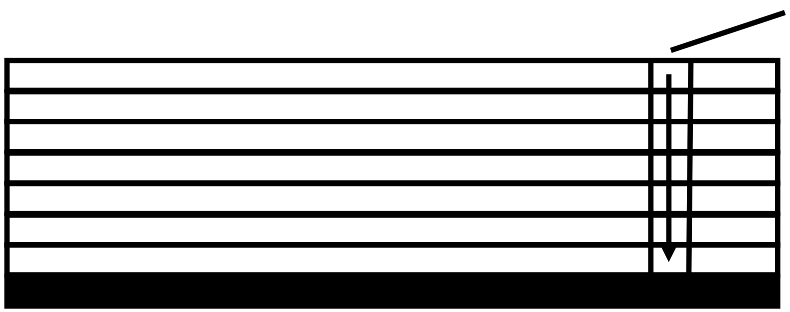
- Often use of TDI (Time Delay and Integration) technology (Ikonos, Quickbird)

  - 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.



A ground sample is imaged by multiple TDI lines, the signal is summed up and shifted to the readout register

Readout register needed to scan from N to S

N

S

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

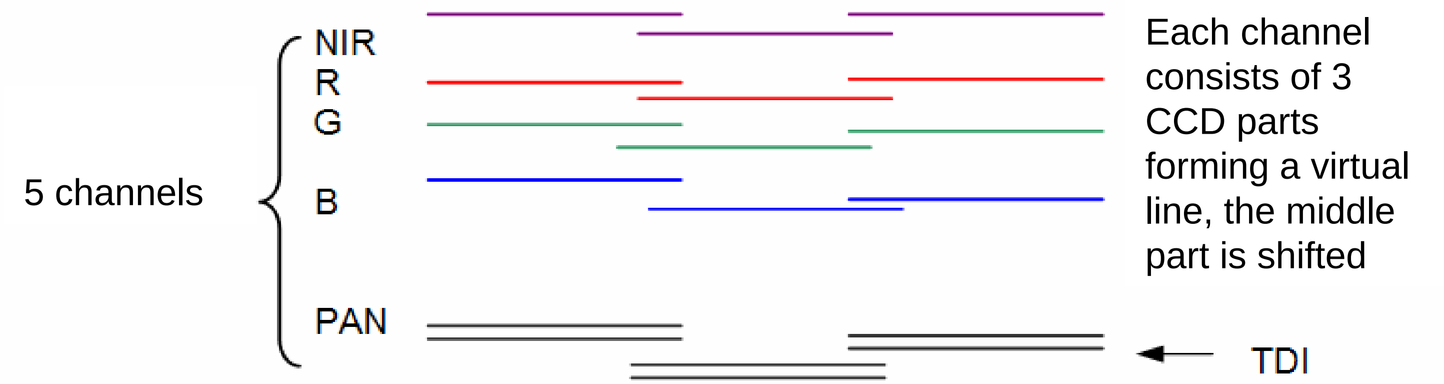
This feature is inferior to TDI, can introduce nonlinearities in the imaging geometry and may cause pixel and edge smearing (unsharpness)

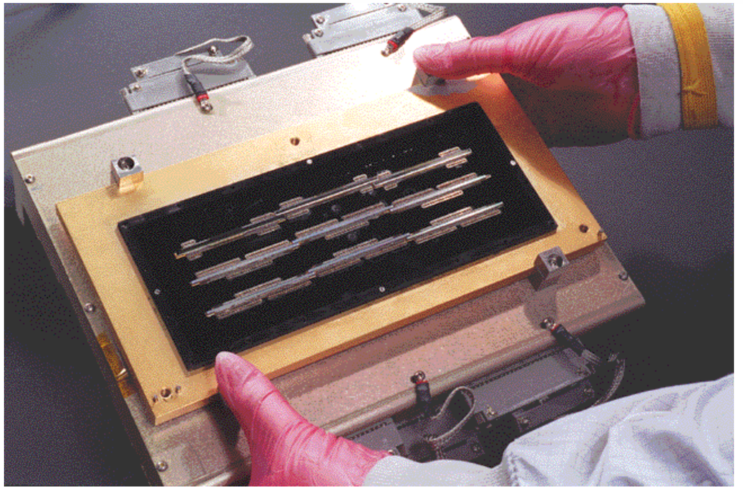
In both cases, the imaged earth part (given often as line scan frequency for line CCDs), is shorter than the ground track of the satellite. A linescan frequency of e.g. 1500 lines/s, means 1/1500 s (0.67 ms) integration time (IT). This is also called asynchronous scanning mode, espec. in case b)

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)

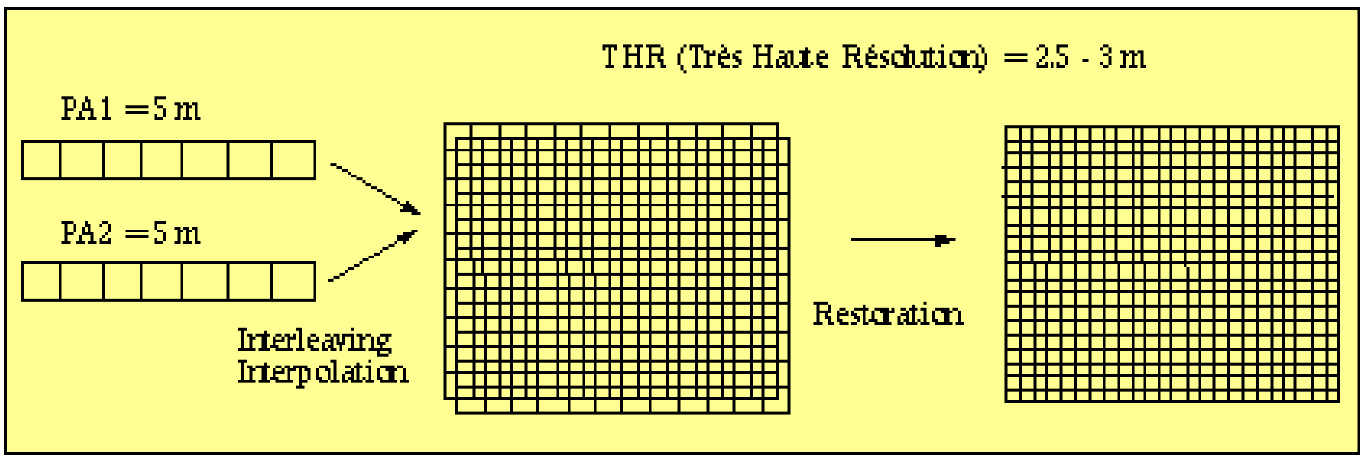
- Reverse TDI PAN (32 lines/stages)

- 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.