Il sistema iperspettrale: applicazioni, metodi e prospettive

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Outline

- Hyperspectral imaging (HSI) and its potentials
- Applications
- HSI in the remote sensing community
- Hyperspectral systems
- Data processing
- Challenges

Hyperspectral imaging

- Measure the *spectrum* of the reflected/emitted radiation, i.e. its distribution as a function of wavelength.
- The observed *radiance spectrum* is physically related to the spectral signature of the observed material (*reflectance* or *emissivity*).
- The high spectral resolution promises great benefits in all the different levels of exploitation of the spectral information using the *continuum spectrum* or investigating specific (diagnostic) *spectral features*
- Increased *complexity* of the processing chain to get reliable *quantitative* information

- ❑ **Quantification**: determines the material abundance.
- ❑ **Characterization**: determines variability of identified materials (e.g. wet/dry sand, soil particle size effects, etc.)
- ❑ **Identification**: determines the unique identity of the foregoing generic categories (e.g. material identification)
- ❑ **Classification**: determines generic categories of the foregoing classes
- ❑ **Clustering**: separates materials into spectrally similar groups
- ❑ **Detection**: Determines the presence of materials, objects, activities or events

Coarse to fine spectral information

Applications (1/2)

Area surveillance

Marine scenario

- Coastal/Littoral control
- Search and Rescue

Land Scenario:

- Area control (defense and security)
- Crime Investigation: (Search of Hidden Vehicles, illegal operations)

Environment

- Pollution
- Illegal waste detection
- Gas emission
- Land use/cover
- Disaster monitoring (prevention, monitoring, post-monitoring)
- Urban growth and industrial area mapping

Water resources

- Water quality
- Toxic algae detection
- Ocean color (OAPs)
- Sources of pollution
- Nutrients loads in fishery
- Oil spill
- Bathymetry

Volcanology

- Volcanic Aerosol emission
- Lava flow parameters
- Lava and hash distribution map

Applications (2/2)

Forestry/vegetation

- Vegetation status indicators
- Stem counts and density estimation
- Gap assessment
- Forest health
- Vegetation species mapping
- Chlorophyll and Nitrogen mapping
- Forest biomass

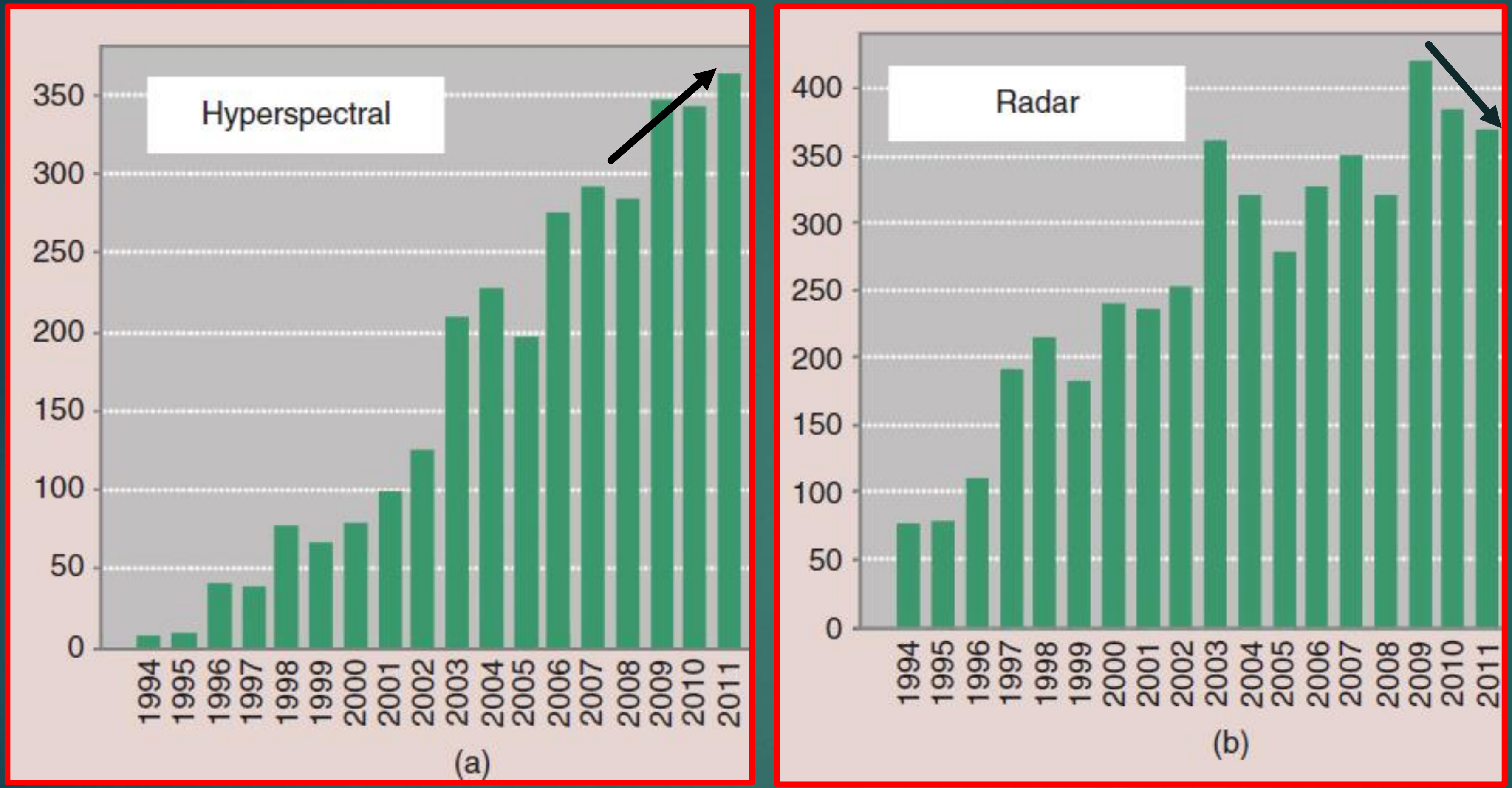
Geology and soil

- Top soil composition
- Mineral mapping
- Mine waste monitoring
- Soil erosion
- Soil salinity

Agriculture

- Crop stress
- Precision farming
- Invasive weed mapping
- Biomass and nitrogen mapping
- Crop growth
- Carotenoid leaf content estimation in vineyards
- Plant health (water, stress, chlorophyll).
- Disease mapping.

Growing interest in the RS scientific community



Number of papers per year in the remote sensing area
on *hyperspectral* and *radar*.

J. M. Bioucas-Dias et al., *Hyperspectral Remote Sensing Data Analysis and Future Challenges*, IEEE GRS Magazine, June 2013

Satellite sensors

Adapted from: J. Transon et alii, *Survey of Hyperspectral Earth Observation Applications from Space in the Sentinel-2 Context, Remote Sensing*, 2018, 10, 157.

Instrument	Hyperion (2000)	TG1 HSI (2011)	PRISMA (2018)	HISUI (2019)	EnMAP HIS (2019)	Shalom (2021)	HyspIRI (2023)
Platform name	EO-1	TianGong-1	PRISMA	HISUI	EnMAP	Shalom	HyspIRI
Swath width (km)	7.5	10	30	30	30	30	185
Spectral range(nm)	357–2576	400–2500	400–2505	400–2500	420–2450	400–2500	380-2510
Spectral bands	220	128	249	185	275	244	214
Spatial resolution (m)	30	10 (VNIR) 20 (SWIR)	30	30	30	10	30
Temporal res. (day)	16–30		14 to 7	2–60	4 (VZA>30)	4 (VZA>30)	<16
Spectral res (nm)	10	10 (VNIR) 23 (SWIR)	10	10 (VNIR) 12.5 (SWIR)	6.5 (VNIR) 10 (SWIR)	10	10
SNR (30% albedo)							
VNIR	140:1 to 160:1		200 in 0.4-1.0 μm 600 @ 0.65 μm	>450@620 nm	400 average >400 @ 0.495 μm	200:1average 600 @ 0.65 μm	560 @ 0.5 μm
SWIR	40:1 to 110:1		200 in 1.0-1.75 μm > 400@1.55 μm 100 in 1.95-2.35 μm > 200 @ 2.1 μm	> 300:1@2100 nm	180 average >180@2200 nm	200 average 400@1550 nm 100 average 200@2100 nm	350@1050 nm 230@2200 nm
Country	USA	China	Italy	Japan	Germany	Italy/Israel	USA
Organization	NASA	Chinese Academy of science and physics	Italian Space agency (ASI)	Japan Ministry of Economy, Trade and Industry	GFZ-DLR	ASI, ISA	JPL/NASA

Airborne sensors: VNIR-SWIR

VNIR-SWIR domain

Manufacturer	Sensor	#Bands	Spectral range (nm)	Spectral resolution (nm)	IFOV (mrad)	FOV (°)/samples
NASA	AVIRIS	224	380-2500	10	1	34°/677
ITRES	CASI-1500H	288	380-1050	2.4	0.49	40°/1500
	SASI	100	950-2450	15	1.2	40°/600
Integrated Spectronics Pty Ltd	HyMap (Probe1)	128 (4 modules VIS NIR SWIR 1 e 2 32 bands each)	450-2480	15-20	2.5	61.3°/512
Specim	AISA-FENIX (ex EAGLE+HAWK)	620	380-2500	3.5 nm (VNIR) 12 nm (SWIR) Var. sampling rate	1.4	32.3°/384
NEO (Norsk Electro Optikk)	Hyspex VNIR 1024	108	400-1000	5.4 nm (sampling)	0.28 (cross) 0.56 (in)	16°/1024
	Hyspex VNIR 1800	182	400-1000	3.26 nm (sampling)	0.16 (cross) 0.32 (in)	17°/1800
	Hyspex SWIR 384	288	1000-2500	5.45 nm (sampling)	0.73	16°/384
Leonardo	Sphyder	240 (VNIR) 266 (SWIR)	400 -1000 (VNIR) 900-2500 (SWIR)	2.5 nm (VNIR) 6 nm (SWIR)	0.73 (VNIR) 1 (SWIR)	29°/1560 (VNIR) 520 m a 1 Km 21.6°/388 (SWIR) 384 m a 1 Km

Airborne sensors: MWIR and LWIR

Manufacturer	Sensor	#Bands	Spectral range (mm)	Spectral resolution (nm)	IFOV (mrad)	FOV (°)/samples
ITRES	TASI	32	8-11.5	250	1.2	40°/600
	MASI	64	3-5	32	1.2	40°/600
Specim	AISA-OWL	96	7.7-12.3	100 (48 sampling)	1.1 (1.5)	24°(32°)/384
NASA	HyTES	256	7.5-12		1.7	50°/512
Telops	Hypercam (FTIR)	N.A. (FTIR)	MWIR e LWIR (different sensors)	(0.25 cm^-1)	0.35(1.4)	6.4°(25°)/ 320

Sit.GA: hyperspectral MWIR+LWIR prototypal sensor being developed by Leonardo within a PNRM project in cooperation with CISAM, CNR-IMAA and University of Pisa.

Thermal HSI potential applications

- Day/night operations.
- Land and sea surface temperature
- High spectral resolution emissivity mapping (minerals, vegetation)
- Gas emission detection

Mini-UAV

https://resonon.com/

- ❑ Low cost
- ❑ High spatial and spectral resolution
- ❑ Simplicity and flexibility
- ❑ Mosaicking for increased area coverage

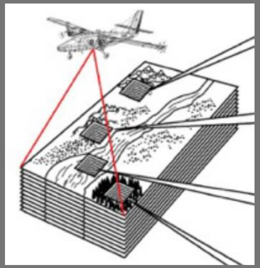
Manuf.	Sensor	Spectral Range (nm)	No. Bands	Spectral Resol. (nm)	Spatial Resol. (px)	Acquis. Mode	Weight (g)
BaySpec	OCI-UAV-1000	600–1000	100	<5 [b]	2048 [d]	P	272
Brandywine Photonics	CHAI S-640	825–2125	260	5 [c] 2.5 [c]	640 × 512	P	5000
	CHAI V-640	350–1080	256	5 [c] 10 [c]	640 × 512	P	480
Cubert GmbH	S 185—FIREFLEYE SE	450–950	125	4 [c]	50 × 50	S	490
	S 485—FIREFLEYE XL	355–750 450–950 550–1000	125	4.5 [c]	70 × 70	S	1200
	Q 285—FIREFLEYE QE	450–950	125	4 [c]	50 × 50	S	3000
Headwall Photonics Inc., Fitchburg, MA, USA	Nano HyperSpec	400–1000	270	6 [b]	640 [d]	P	1200 [e]
	Micro Hyperspec VNIR	380–1000	775 837 923	2.5 [b]	1004 [d] 1600 [d]	P	≤3900
HySpex	VNIR-1024 Mjolnir V-1240 HySpex SWIR-384	400–1000 400–1000 1000–2500	108 200 288	5.4 [c] 3 [c] 5.45 [c]	1024 [d] 1240 [d] 384 [d]	P P P	4000 4200 5700
MosaicMill	Rikola	500–900	50 [a]	10 [b]	1010 × 1010	S	720
NovaSol	vis-NIR microHSI	400–800 400–1000 380–880	120 180 150	3.3 [c]	680 [d]	P	<450
	Alpha-vis micro HSI	400–800 350–1000	40 60	10 [c]	1280 [d]	P	<2100
	SWIR 640 microHSI	850–1700 600–1700	170 200	5 [c]	640 [d]	P	3500
	Alpha-SWIR microHSI	900–1700	160	5 [c]	640 [d]	P	1200
	Extra-SWIR microHSI	964–2500	256	6 [c]	320 [d]	P	2600
PhotonFocus	MV1-D2048x1088-HS05-96-G2	470–900	150	10-12 [b]	2048 × 1088	P	265
Quest Innovations	Hyperea 660 C1	400–1000	660	-	1024 [d]	P	1440
Resonon	Pika L Pika XC2 Pika NIR Pika NUV	400–1000 400–1000 900–1700 350–800	281 447 164 196	2.1 [c] 1.3 [c] 4.9 [c] 2.3 [c]	900 [d] 1600 [d] 320 [d] 1600 [d]	P P P P	600 2200 2700 2100
SENOP	VIS-VNIR Snapshot	400–900	380	10 [b]	1010 × 1010	S	720
SPECIM	SPECIM FX10 SPECIM FX17	400–1000 900–1700	224 224	5.5 [b] 8 [b]	1024 [d] 640 [d]	P P	1260 1700
Surface Optics Corp., San Diego, CA, USA	SOC710-GX	400–1000	120	4.2 [c]	640 [d]	P	1250
XIMEA	MQ022HG-IM-LS100-NIR	600–975	100+	4 [c]	2048 × 8	P	32
	MQ022HG-IM-LS150-VISNIR	470–900	150+	3 [c]	2048 × 5	P	300

Adão, T., et alii, *Hyperspectral Imaging: A Review on UAV-Based Sensors, Data Processing and Applications for Agriculture and Forestry*, Remote sensing, 9(11) 2017,

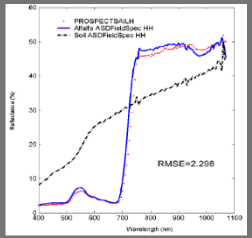
HSI data exploitation workflow

Mission planning

HSI
data acquisition



Ancillary
data acquisition
(Lab., ground)



Instrument related processing

Noise sources characterization

Calibration:
- Radiometric
- Spatial
- Spectral

Radiance
Geocoded
(lat/long)

Pre-processing

Quality improvement:
- Non-uniformity
- Artifacts
- Filtering

Complexity reduction
- Feature selection
- Band selection

Spatial/geo.
- Orthorectification
- Coregistration

Atmospheric corr.
- In-scene (ELM)
- Physical model
- TES

Geocoded
reflectance/emissivity

Application driven processing

Spectrum "Continuum"
- Classification
  - Clustering
  - Supervised
- Object detection
  - Anomaly detection (unsup.)
  - Signature based (supervised)
- Unmixing

Spectroscopy oriented
- Physical parameters estimation
- Band ratios
- OAPs
- Gas detection and estimation

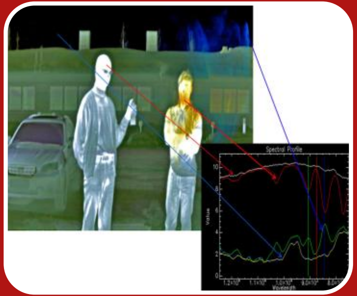
Multitemporal
- Change detection
- Change classification
- Dynamic events tracking

Products

Challenges: systems and technology

Mini-UAV

- Reduced weight and size
- Applications, methods, platforms
- Proof-of-concept for sensors, sensors integration, data quality and accuracy



MWIR and LWIR

- Technology
- Physics models
- Temperature emissivity separation

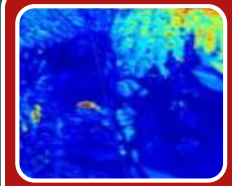
Sensor fusion/integration

- Improving spatial, spectral, temporal information
- Lidar/stereo images (3D maps for atmospheric correction, orthorectification 4D maps – x, y, z, λ)
- Integrated systems in wide area surveillance (HSI + broadband)

Challenges: data processing

Atmospheric correction
- ❑ Shadows, clouds
- ❑ 3D terrain models
- ❑ Automatic and unsupervised
- ❑ Fast methods (real-time)

Detection
- Estimate background/target with limited training data.
- Sparsity
- Non-linear methods (beyond covariance matrix: kernels)



Unmixing
- Nonlinear models
- Subpixel endmembers (statistical approaches)
- Methods inherited from array processing (radar)

Classification
- Methods based on nonlinear structures (manifold learning)
- Fusion of different algorithms

Fast Computing
- Computationally aware algorithms
- Clusters and distributed architectures (offline)
- FPGA and GPU (onboard, real-time)

New data sets equipped with accurate ground truth for the development and assesment of new applications and processing solutions

New paradigms expected from interaction with the ML and AI communities and from big data analysis (HSI satisfy the 4V requisites!)

Thanks for your attention!